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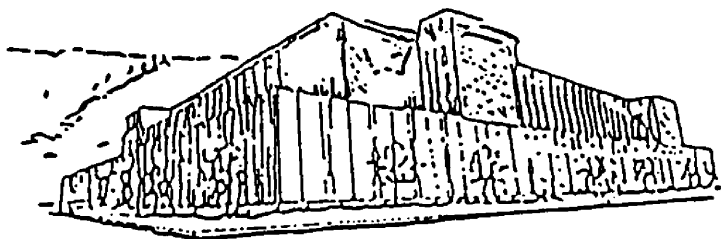
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A STUDY ON AUTOMATED DASYMETRIC MAPPING

by

Yanbing Tang

M.S., Hangzhou University, 1988

presented in partial fulfillment of the requirements

for the degree of

Master of Arts

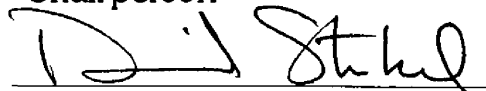
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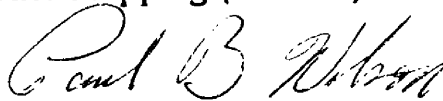
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A Study on Automated Dasymetric Mapping (92 PP.)

Advisor: Dr. Paul B. Wilson



Dasymetric mapping is one of the traditional techniques of thematic mapping. It is used for representing volumetric quantitative data on maps. This technique is particularly suitable for portraying phenomena that are not distributed in a uniform or continuous manner. It has been commonly used for population and other density mapping. However, the automation of this traditional thematic mapping technique is a problem that has never been solved. The purpose of this study is to attempt to adapt this traditional technique to available GIS and computer mapping software packages for the purpose of automation.

This study begins by discussing the traditional dasymetric mapping technique--its varieties, uses, and methodologies. Then it focuses upon the current status of automation. On the basis of the traditional procedures of dasymetric mapping and the principles of GIS, a design for automated dasymetric mapping using a GIS is specified, and demonstrated through the use of an actual example--Missoula urban area population density distribution. The entire procedure is accomplished using current GIS and mapping software packages, mainly IDRISI and Atlas GIS. The example study provides answers to many of the questions that concern the process of automating the technique. Finally, suggestions are made for the future design of a single set of software for dasymetric mapping.

The implementation of this study indicates that the problem of automating dasymetric mapping is much more complex than it is for choroplethic or isoplethic mapping. This is primarily because a greater amount of analysis of both spatial and non-spatial attributes is involved. Although a single mapping software package for automated dasymetric mapping is not yet available, almost all tasks involved can be implemented by using a GIS. For the best result, a GIS working with both raster and vector data structures should be used for automated dasymetric mapping. It is also been pointed out that the cartographer plays an important role in automated dasymetric mapping.

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I wish to express my sincere gratitude to Dr. Paul B. Wilson, my advisor and committee chairman, for his guidance, patience and expertise. I am also grateful to Dr. John J. Donahue whose valuable advice and friendship have been greatly appreciated. I wish to extend my thanks to the other members of my committee, Dr. Alden H. Wright and Mr. Steven Holloway, for their help and support; to Mrs. Nancy Ebel for her help and concern; to Mr. Pat O'Herren for providing me with the image--the Missoula Land Cover Types.

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My heartfelt thanks go to my mother and sisters. Their understanding and encouragement have supported me through my graduate program.

I dedicate this thesis to the memory of my father.

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Chapter One

INTRODUCTION

The dasymetric mapping technique is one of three traditional methods of thematic cartography. The other two include the choroplethic and the isoplethic mapping techniques. All three are used for representing volumetric quantitative data on maps with areal symbols.¹

In each instance, areas of the map are shaded or colored to represent different ranges of data values according to a preconceived frequency distribution. Choroplethic mapping involves filling different enumeration districts, such as counties or census tracts, with different colors or shades. Each shade or color represents one of the categories in the frequency distribution. Isoplethic mapping involves attaching the value of each enumeration district to an internal control point (usually the centroid) and using all of the control points within the area of the map to interpolate the positions of isolines. The areas between the isolines may then be given different shades or colors to represent the values of the categories.

¹Geographical volumes are three-dimensional in concept. Such data may range from a mental construct, or they can be tangible. For a more detailed explanation, see Arthur Robinson et. al. , Elements of Cartography, 6th ed., (New York: John Wiley and Sons, 1995), 108.

Dasymetric mapping is similar to the two other techniques except that the extent of the enumeration districts are manipulated in order to produce areas which have relatively uniform densities throughout. A map showing population density might provide a good example. Within a single census tract the population density might vary considerably. One portion of the area might be quite densely settled, while the other may have only few people. The dasymetric method would separate the census tract into two or more areas and would shade each of these areas as appropriate in order to correspond to the density distribution.

Neither the choroplethic nor the isoplethic technique is as well suited for displaying discontinuous and nonuniform data as is the dasymetric map. On the one hand, the choropleth map, being restricted to the original pattern of enumeration districts, is unable to take into account variations which may occur from place to place within each area.² On the other hand, the isopleth map does not allow for areas of very high value to be placed in immediate juxtaposition with areas of low value since the entire sequence of isolines must occur between the high and low values.³ Dasymetric mapping overcomes both of these limitations.

However, dasymetric mapping requires a great deal of supplemental

²J. Campbell, *Introductory Cartography* (Dubuque, IA: Wm.C.Brown Publishers, 1991), 224.

³K. C. Clarke. *Analytical and Computer Cartography* 2d ed (Englewood Cliffs, N.J.: Prentice Hall, 1995), 285.

information for the spatial manipulations which are needed to divide the enumeration districts into logical divisions. It also requires the analysis of several kinds of spatial and non-spatial data. The spatial data are analyzed in order to manipulate the size and shape of the enumeration units. The non-spatial data are analyzed in order to manipulate the attribute data so that they may be made to intelligently fit into these enumeration units. In addition, personal judgment, which employs the cartographer's knowledge concerning the topic being mapped and the area, is involved in this technique. So, if sufficient information is available, and if the work is carefully and responsibly done, this technique will result in a detailed and realistic product.⁴ But the method is very tedious using the traditional procedures of thematic cartography.

Not a great amount of research has been done on the dasymetric mapping technique, let alone on automated dasymetric mapping. This has to do chiefly with status of research concerning traditional dasymetric mapping. Journal articles concerning dasymetric technique are very rare compared to other techniques. Only a few published articles focused on this technique were found.⁵ Most published journal articles merely discuss this technique briefly, usually in conjunction with other techniques when dealing with population density mapping.⁶

⁴Ibid., 226.

⁵An example of one of the better articles is J. K. Wright. "A Method of Mapping Density of Population, with Cape Cod as an Example." Geographical Review 26(1936): 103-110.

⁶An example is O. M. Dixon. "Methods and Progress in Choropleth Mapping of Population Density." The Cartographic Journal 9 (1, 1972): 19-29.

Moreover, M.A. theses and PH.D. dissertations concerning the dasymetric mapping technique are also very few. George F. McCleary's dissertation "The Dasymetric Method in Thematic Cartography" finished in 1969 is the most complete study of the traditional technique to date.

Not only has dasymetric mapping suffered because of insufficient research, but the literature is filled with examples of contradictory terms and unclear concepts. Although dasymetric method were used quite often to make published maps, it is rare indeed that any indication is given of exactly how the principle was applied when the map was created.⁷ In some cases, the dasymetric mapping technique is treated as a supplementary category of choroplethic mapping; in others it has been considered a separate technique on its own.

In current books dealing with cartography and map reading, the dasymetric mapping technique is handled in three different ways: (1) it is neither recognized as a separate thematic technique nor discussed;⁸ (2) it is discussed but only in terms of a supplementary category of choropleth technique;⁹ (3) it is recognized as one of the three methods of mapping quantitative data by areal symbols.¹⁰

As to automated dasymetric mapping, the author has not found even one

⁷Ibid, 24.

⁸B. D. Dent. Cartographer: Thematic Map Design, 3d ed (Dubuque, IA: Wm. C. Brown Publishers, 1993).

⁹M. S. Monmonier and G. A. Schnell. Map Appreciation (Englewood Cliffs, N.J.: Prentice Hall, 1988).

¹⁰A. H. Robinson. Elements of Cartography, 6th ed (N.Y.: John Wiley & Sons, 1995).

article focusing on the topic. Just two sources, an article and a book, briefly mention it, but they give only limited comments and do not seriously discuss how the automation might take place. The comments from these sources can be categorized into three general types--those which deal with the possibility of automated dasymetric mapping, those which state the problem involved, and those which discuss the advantages of implementing the technique. The following quotes typify these comments:

1) Dealing with the possibility

"Within a GIS, production of a dasymetric map is not a trivial problem, but equally is not impossible. Effectively all the tools required are available, so long as a GIS is vector based, and/or it is possible to address polygon attribute."¹¹

2) Stating the problem involved

"The essential problem in dasymetric mapping using GISs is to peruse existing sources to select the best possible supporting information."¹²

3) Discussing the advantages

"Using geographic information systems (GISs) to access these databases has greatly simplified the dasymetric technique and is popularizing its use."¹³

Of the three traditional cartographic approaches discussed earlier, the one

¹¹P. F. Fisher. "Knowledge-based approaches to determining and correcting areas of unreliability in geographic databases." In The accuracy of Spatial databases edited by M. F. Goodchild and S. Gopal (Bristol, PA: Taylor & Francis, 1989), 49.

¹²A. H. Robinson et al., Elements of Cartography, 6th ed (N.Y.: John Wiley & Sons, 1995), 523.

¹³Ibid.

that has most commonly been automated is the choroplethic mapping technique. There are numerous examples of existing software packages which include automated choroplethic mapping.¹⁴ Also the software for automated isoplethic mapping is readily available. SURFER is one example.¹⁵ Only automated dasymetric mapping continues to be a problem. To date, there is no single software package which has the expressed capability to accomplish dasymetric mapping, although, as shall be seen, the analytical functions of several of the more capable GIS packages may be combined for that end.

One may safely conclude that the failure to computerize dasymetric mapping stems not only from the complexity of the traditional technique but also from difficulty of coding those procedures for the computer. As a result, the only choices left to the computer cartographer is either choroplethic or isoplethic mapping. While these are extremely useful mapping techniques, nevertheless, the robustness of thematic cartography is seriously diminished without the dasymetric method. Dasymetric mapping should be computerized. This thesis is devoted toward this end.

The Problem

It was mentioned above that to date there is no available software package

¹⁴These software packages include ARC/INFO, Atlas GIS, MapViewer, MapInfo, PAMAP, MOSS, GRASS, etc.

¹⁵SURFER is developed by Golden Software, Inc. and designed to produce maps of both two- and three-dimensional surfaces from randomly spaced data.

for automated dasymetric mapping. This problem, of course, has hindered the progress of such mapping. Besides the lack of a software package, the other main problem concerned with dasymetric technique resides in its data requirements. One of the most distinct characteristics of dasymetric mapping is that the method requires a great deal of additional information because nothing in the original data set can help the cartographer decide where the uniform areas and zones of abrupt change are located. Without the availability of this additional information, dasymetric mapping is impossible. As the method was originally practiced, the required information is very difficult or very expensive to obtain. Even after the cartographer had obtained all of the needed information, analyzing and manipulating it manually was excessively tedious. This sets limits on the use of the technique even as was traditionally practiced.

Accordingly, the problem to be dealt with in this thesis is as follows:

This thesis will explore current GIS and mapping software packages, and show how they can be used to automated dasymetric mapping.

There are several subsidiary questions involved in the attempt to solve this problem. Is automated dasymetric mapping possible or does it present some insurmountable obstacles? If it is possible, how can it be approached? If there are some obstacles, what kinds of obstacles are they? If the method is impossible, then what are the alternatives? Answers to these related questions will be the foci of this study.

Methodology

The intention of this study is to find answers to the questions noted above. These questions are not intended to be used as hypotheses which are to be either proved or disproved. They are intended to help summarize the problems involved and to stimulate a search for possible answers. This requires that the author familiarize herself with the traditional dasymetric mapping technique, especially its principles and methodology, before making an attempt to search out ways to automate it.

Therefore, the study began by searching and studying the literature regarding dasymetric mapping. One thing sought was an acceptable definition of the method, its varieties, and its uses. The current status of automation of the technique was also researched. Next, a survey of thematic maps in more than forty atlases,¹⁶ which were published in different time periods and for different countries, was made. The objective of this survey was to familiarize the author with the ways in which the traditional technique had been used in thematic cartography. Based on the information obtained from this survey, the population density of the Missoula urban area was chosen as the mapping theme for this study, partly because population density is the most popular theme of dasymetric maps, and partly because the necessary data were readily available. After performing the survey, the possibilities of automated dasymetric mapping were evaluated with reference to the general procedure of making a dasymetric map

¹⁶See the list in "Bibliography".

and principles of geographic information systems. In addition, some current GIS and mapping software packages were reviewed from the standpoint automated dasymetric mapping. Finally, a design for automated dasymetric mapping using GIS was specified, and its applicability was demonstrated by an actual example--the Missoula urban area population density distribution. The GIS and mapping software packages which were mainly used for the project involved IDRISI¹⁷ and Atlas GIS.¹⁸

An Overview

This thesis contains five chapters. Chapter One is introductory. In Chapter Two, the general procedure of dasymetric mapping is discussed. Special attention is given to the dasymetric mapping technique--its varieties, its uses, and its methodology. Attention is also given to the current situation of automated dasymetric mapping. Chapter Three places emphasis on how automated dasymetric mapping can be approached through the use of various GIS software packages. A design for automated dasymetric mapping using these GIS packages is specified. Chapter Four focuses on making a dasymetric map of the population density of the Missoula urban area using the procedure outlined in Chapter Three. In addition, the possible errors and merits of automated dasymetric mapping are

¹⁷IDRISI is a grid-based Geographic information Systems and developed by the Graduate School of Geography at Clark University.

¹⁸Atlas GIS is a vector-based desktop Geographic Information Systems and developed by Strategic mapping, Inc.

briefly discussed in Chapter Four. Chapter Five concludes the study. It summarizes what was done and outlines the tasks remaining to be done. In addition, it gives some suggestions for the future design of a single set of software for automated dasymetric mapping.

Chapter Two

THE DASYMETRIC MAPPING TECHNIQUE

Definition of Dasymetric Mapping

The word dasymetric is derived from the Greek words "dasys", thick or dense, and "metron", measure. Thus, dasymetric means "density measure". The term "dasymetric" was first used by a Russian cartographer, Semenov-Tian-Shansky, in 1923 to describe his population density map.¹ Since then, this term has slowly come to be accepted "as the designation for a distinct class of cartographic presentations."²

Arthur H. Robinson is the first author who treated the technique in generic terms.³ In his book "Elements of Cartography", he described the dasymetric mapping technique along with the isoplethic and choroplethic mapping techniques as three methods of mapping quantitative data with area symbols. In "Elements of Cartography", the dasymetric technique is described as follows:

"Choropleth maps reflect the structure of data collection units. When these units are poorly matched to the character of a geographic distribution, the choroplethic technique can mask a great deal of

¹G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (PH.D. diss., University of Wisconsin, 1969), 22.

²Ibid.

³Ibid., 23.

information. In this situation, dasymetric mapping offers an effective alternative.

The dasymetric map is often made from the same data as the simple choropleth map. But it assumes areas of relative homogeneity, separated by zones of abrupt change."⁴

Thus, the dasymetric mapping technique presents a pattern of areas which are relatively statistically uniform. The boundaries of these areas are placed in parts of the map characterized by abrupt changes in distribution or density.

Before a map can be included within the dasymetric class, two criteria must be met: (1) a statistical surface has to be defined;⁵ (2) the zones or boundaries of abrupt change in value between areas of relative homogeneity have to be defined. These two criteria are easy to understand. A statistical surface is one of the most important concepts in cartography. It can be assumed to exist for any distribution that can be conceived of as being mathematically continuous over an area and measured on an ordinal, interval, or ratio scale of measurement.⁶ The task of the cartographer is to select proper technique to portray the statistical surface by point, line, or area symbols. Actually, all thematic maps show various statistical surfaces in different ways. Therefore, a statistical surface is necessary for any mapping technique. As for the second criterion, it is also easy to understand. The dasymetric map assumes the existence of areas of relative homogeneity

⁴A. H. Robinson et al., *Elements of Cartography* 6th ed (New York: John Wiley & Sons, 1995), 519.

⁵G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (PH.D. diss., University of Wisconsin, 1969), 19.

⁶A. H. Robinson et al., *Elements of Cartography* 6th ed (New York: John Wiley & Sons, 1995), 281.

separated from one another by zones of rapid change. It is the zones or boundaries between areas of relative homogeneity that differentiate dasymetric maps from choropleth maps.

How Dasymetric Maps Are Used

As one of the traditional techniques of thematic mapping, dasymetric mapping is used to represent quantitative data with areal symbols. Historically, it was commonly used to map population densities. Therefore, some people misunderstood, believing that population density was the unique concern of dasymetric mapping. Actually, it can be used in any situation in which the cartographer feels it suitable to present quantitative area distributions as areas of relatively uniform density separated by areas of abrupt change.⁷

Some of the initial research involved in this thesis included an examination of thematic maps in more than forty atlases.⁸ These atlases were published at different times in several different countries. The research revealed that the dasymetric mapping was used to represent quantitative volumetric data in many of the atlases, especially in some of the high quality atlases such as "Goode's World Atlas".⁹ The theme addressed most frequently by the dasymetric maps was population density. Besides mapping population density, the dasymetric

⁷G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (PH.D. diss., University of Wisconsin, 1969), 109.

⁸See the list in "Bibliography".

⁹Edward B. Espenshade, Jr. Goode's World Atlas, 18th ed (Chicago: Rand McNally & Company, 1993).

technique was also used to map landforms,¹⁰ rock ore content,¹¹ percentage cropland, percentage woodland, etc.

Although population density is not the unique theme for dasymetric mapping, it is the most popular. Consequently, this study will use population density distribution as a working theme.

A Comparison of Dasymetric and Choroplethic Mapping

A useful exercise at this point would be to compare and contrast choroplethic and dasymetric mapping. The choroplethic technique maps a distribution by means of administrative or political enumeration units which were likely created originally to serve some administrative purpose. Thus, these units seldom coincide with the actual distribution pattern. However, mapping unit boundaries are independent of the enumeration boundaries in dasymetric maps. Therefore, the dasymetric technique presents a pattern of areas of statistical uniformity separated by boundaries of abrupt change. These boundaries are a reflection of an actual division in the distribution.¹²

At this point, it might be concluded that choroplethic technique is "more of

¹⁰G. H. Hammond, "Analysis of Properties in Land Form Geography: An Application to Broad-Scale Land Form Mapping," Annals of A.A.G. 54 (1964): 11-19.

¹¹K. C. Clarke, Analytical and Computer Cartography, 2d ed (Englewood Cliffs, N.J.: Prentice Hall, 1995), 285.

¹²G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (Ph.D. diss., University of Wisconsin, 1969), 125.

a statistical than a geographic tool",¹³ and the dasymetric technique is just the opposite of the choroplethic technique. The dasymetric map more closely resembles the statistical surface; as a result, it portrays the actual distributions of the phenomena being mapped more accurately than does the choropleth map. Conversely, the dasymetric mapping technique is more complicated than the choroplethic technique and requires a great deal of additional information to effect.

Automated choropleth mapping is relatively simple. Even a person with no cartographic training can make a choropleth map very quickly with a mapping software package designed for that purpose. This has facilitated the wide usage of the technique in thematic mapping. However, one must be aware that choroplethic mapping works well only when its assumptions are acceptable to the cartographer and to the map reader. The most important assumption made in choroplethic mapping is that the phenomenon being mapped in every enumeration unit is distributed uniformly throughout that unit. Actually, many phenomena are not uniformly distributed in the units for which the data are collected. A very good example of this is population density. Without question, if the choropleth map is used to represent the population density of a county, the map would not be very accurate since most of the population of the county unit will ordinarily be concentrated in the towns located within that unit. This

¹³Ibid., 25.

shortcoming was first noticed at least twenty years ago:¹⁴

"Density maps, commonly shown in census atlases, can tend to project erroneous impressions also. The usual (choropleth) map of this type shows population distribution as evenly spread throughout a certain designated area; in actual fact, such an apportionment is more unusual than usual."

Consequently, when the cartographer is dissatisfied with choroplethic mapping, dasymetric mapping provides a good alternative. This may well be the reason why dasymetric mapping is sometimes considered "a refinement of the choropleth method".¹⁵

The Varieties of Dasymetric Maps

Although all dasymetric maps attempt to present the spatial distributions of phenomena as areas of relative uniform distribution separated by zones of abrupt change, they may be compiled by several different procedures. Therefore, dasymetric maps can be classified into different types according to the methods by which they are compiled. George F. McCleary's dissertation "The Dasymetric Method in Thematic Cartography" is the most complete study of this traditional technique to date. In this dissertation, he described seven types of dasymetric maps based on the various methods by which these maps have been compiled. The seven types are:¹⁶

¹⁴M. Gordon, "Cartography for Census Purposes," World Cartography 13 (1975): 18.

¹⁵A. H. Robinson, Early Thematic Mapping in the History of Cartography (Chicago: The University of Chicago Press, 1982), 199.

¹⁶*Ibid.*, 130.

1. The "Pure Dasymetric": Actual Areal Delineation of the Distribution.
2. The Highly General Case, with no Distinct Methodology.
3. Dasymetric Zones Synonymous with Choroplethic Units.
 - A: Use of Small-Sized Statistical Units.
 - B: Maps Based on "Appropriately Defined" or Other Areal Units Closely Associated with the Distribution.
4. Corrupted Choroplethic Maps as Dasymetric Presentations.
 - A: Areal Subdivision and/or Elimination.
 - B: Boundary Rounding.
 - C: Grouping of Areal Units.
5. Use of Other Regions with the Assumption of Correlation.
6. Density Zones Outlining.
7. Internal Adjustment.

Although dasymetric maps may be compiled from different types of original data by any one of the more or less related procedures listed above,¹⁷ they are all designed to achieve the same purpose--that is, to present a statistical surface composed of areas of uniform statistical values separated by zones or boundaries of rapid change in value.

Actually, among the seven types just listed, the third, fourth, fifth and seventh types are all very closely related to choropleth maps. Hence, grouping them together seems reasonable. After this grouping, there are four different types of dasymetric maps including:

1. Pure Dasymetric.
2. Highly General Dasymetric.
3. Density Zones Outlining.
4. Choropleth Dasymetric.

¹⁷Ibid., 133.

Except for the first type, the "pure dasymetric" map derived by delineating the distribution directly, all of the other types of dasymetric maps depend on a great deal of additional geographic information. Nothing in the original data will help the cartographer decide where to position dasymetric boundaries. Instead, this information must come from various other external sources which concern the spatial relationships involved.¹⁸

The Methodology of Dasymetric Mapping

It has been stated above that there are four methods of making dasymetric maps which share the same purpose--to show the distribution of phenomenon by means of uniform areas separated by zones or boundaries of abrupt change. These have resulted from the highly complicated nature of the historical evolution of dasymetric mapping which has produced several somewhat related techniques instead of a single dasymetric method.¹⁹ All of the techniques are designed to achieve the same purpose. They are described in the sections which follow.

Pure Dasymetric Mapping

The pure dasymetric map is the only variety which can be derived directly by making an actual area delineation of a distribution without resorting to the use of other additional information. It requires that "data are available at an infinite

¹⁸A. H. Robinson et al., *Elements of Cartography* 6th ed (New York: John Wiley & Sons, 1995), 523.

¹⁹G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (PH.D. diss., University of Wisconsin, 1969), 133.

number of points".²⁰ In other words, it requires that information at every point regarding the entire statistical surface be present. This requirement has made this method uncommon and only applicable to some types of topographic phenomena.

Highly General Dasymetric Mapping

The highly general dasymetric map is the simplest dasymetric map and is usually drawn at small scale. This kind of dasymetric mapping lacks a distinct methodology in its compilation. It can be derived in at least two ways: (1) by reducing the complexity of the representation derived from a dasymetric map produced at larger scale; or (2) by rounding the boundaries and grouping values which appear on a very detailed choropleth map.²¹ In either case the map information becomes highly generalized in the process.

This method was developed more than a century ago when there was a relative lack of data. Today, with the availability of a great deal of spatial and non-spatial attribute data, as well other information, the technique obviously has become out-dated.

Density Zones Outlining Dasymetric Mapping

This type of dasymetric map is derived from a dot map and does not require additional information. The cartographer makes a dasymetric map out of

²⁰Ibid., 134.

²¹Ibid., 140.

a dot map by converting dot density distributions into dasymetric zones. If a dot map is highly accurate, the dasymetric map derived from it will be accurate too. This method is simple, but some people think it is a poor way to present the data because it "can not produce results any better than the quality of the original dot map".²² Moreover, if a detailed dot map is not available, the cartographer still has to use other methods to derive a dasymetric map or build a dot map first.

Choropleth Dasymetric Mapping

This type of dasymetric map is made from the same data as the simple choropleth map. Since many types of data are gathered on the basis of either political or administrative districts, this type of dasymetric map is the most common type. In order to derive a dasymetric surface from choropleth units, the cartographer follows a sequence of procedural steps. For different situations, there are different procedures. Three types of procedures are discussed here. They include (1) finding dasymetric zones which coincide with choropleth units, (2) adjustment of corrupted choropleth maps and (3) internal adjustment.

Finding Dasymetric Zones Which Coincide with Choropleth Units

Sometimes, choropleth units (that is enumeration units) coincide with dasymetric zones. There are two cases:

- 1) when very small statistical units are used in the mapping process;

²²D. M. Dixon, "Methods and Progress in Choropleth Mapping of Population Density," The Cartographic Journal 9(1972): 29.

- 2) where there is a high degree of correspondence between elements of the enumeration units and the distribution, either "accidentally" or by design.²³

Under these two circumstances, the concept of a choropleth map blends into that of a dasymetric map. Although the map still resembles a choropleth map, it is actually a dasymetric map. This kind of dasymetric map, however, is quite uncommon since administrative or political units seldom coincide with the actual distribution pattern.

Adjustment of Corrupted Choropleth Maps

Corrupted choropleth maps are those maps in which some of the statistical units reflect the pattern of the actual distribution being mapped and others do not. Parts of such maps can be recognized as dasymetric while the other parts are distinctly choropleth.

For corrupted choropleth maps, two kinds of adjustments can be performed in order to get dasymetric representations. One involves areal grouping, subdivision, and elimination. The second involves boundary rounding.

Areal Grouping, Subdivision, and Elimination

This adjustment includes three basic operations: areal grouping, subdivision and elimination. The cartographer, who intends to define uniform areas and

²³G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (PH.D. diss., University of Wisconsin, 1969), 144.

zones of abrupt change, can adjust choropleth units based on additional information. Smaller enumeration units of the same density can be grouped into larger segments. Larger enumeration units with different densities can be divided into several smaller segments with different densities. Some enumeration units that have nothing to do with the mapped phenomenon, such as uninhabited units in a population density map, can be eliminated.

Boundary Rounding

This operation alters the boundaries of enumeration units by rounding or smoothing them in order to add some areas "to the areas of adjacent units segments which are presumably more nearly equivalent to them in value or characteristics than they were to the original unit".²⁴ For example, a census block may be mainly occupied by a park with only one or two residential houses in one corner. If the block right next to this corner is a residential block, this corner might be added to that block by altering the boundary between the two blocks, in other words, by rounding or smoothing the boundary of the residential block.

Internal Adjustment

This is the most complicated way to derive a dasymetric surface. It internally adjusts the surface formed by choropleth units to create a dasymetric surface. In order to modify the original enumeration units for data collection and to derive uniform areas and zones or boundaries of abrupt change, the

²⁴Ibid., 155.

cartographer needs to know the spatial distribution of several variables which influence the distribution of the phenomenon being mapped. Also the relationships between these variables and the phenomenon being mapped must be considered. These variables are of two kinds: limiting variables and related variables.²⁵

Limiting Variables

Limiting variables set an absolute upper limit on the quantity (percentage or density) of the mapped phenomenon which can occur in an area. Based on the relationships between a limiting variable and the phenomenon, as well as knowledge of the area, the cartographer can adjust or modify the enumeration units using those methods mentioned above, and can recalculate the distribution density using the following formula:²⁶

$$D_n = (D - (D_m * a_m)) / (1 - a_m)$$

where D : density of the overall region

D_m : estimated density of region m

a_m : fraction of total area in region m

$1 - a_m$: fraction of total area in region n

D_n : density assigned to region n .

²⁵A. H. Robinson et al., *Elements of Cartography* 6th ed (New York: John Wiley & Sons, 1995), 523-524.

²⁶J. Campbell, *Introductory Cartography* (Dubuque, IA: Wm. C. Brown Publishers, 1991), 225.

Traditionally, D_m and a_m are estimated by the cartographer based on additional information. But now, particularly with the development of computer technology, many kinds of data collection are very complete and detailed. For example, census population data are now collected for individual block areas, whereas previously they were collected only for census tracts. Many census blocks are so small that the cartographer can directly calculate the population densities for blocks without estimating D_m and a_m .

A simple process of using limiting variables to define a dasymetric surface is shown in Figure 1. The mapping theme is the percentage of cropland in an agriculture area. Panel A is a choropleth map. The limiting variables used in this example are urban land use and percentage woodland. Their distributions in the study area are shown in Panel B and C respectively. In urban land use areas, the percentage of cropland is zero. In woodland areas, the percentage of cropland varies based on the percentage of woodland. Generally, if the percentage of woodland is higher, the percentage of cropland is lower, and vice versa. According to the relationships between them, the percentage of cropland can be recalculated using the formula given above. At the same time, the boundaries of different percentage values can be adjusted. These new boundaries are different from the original enumeration boundaries. The result is shown in Panel D.

Related Variables

Related variables are those geographic phenomena "that show predictable

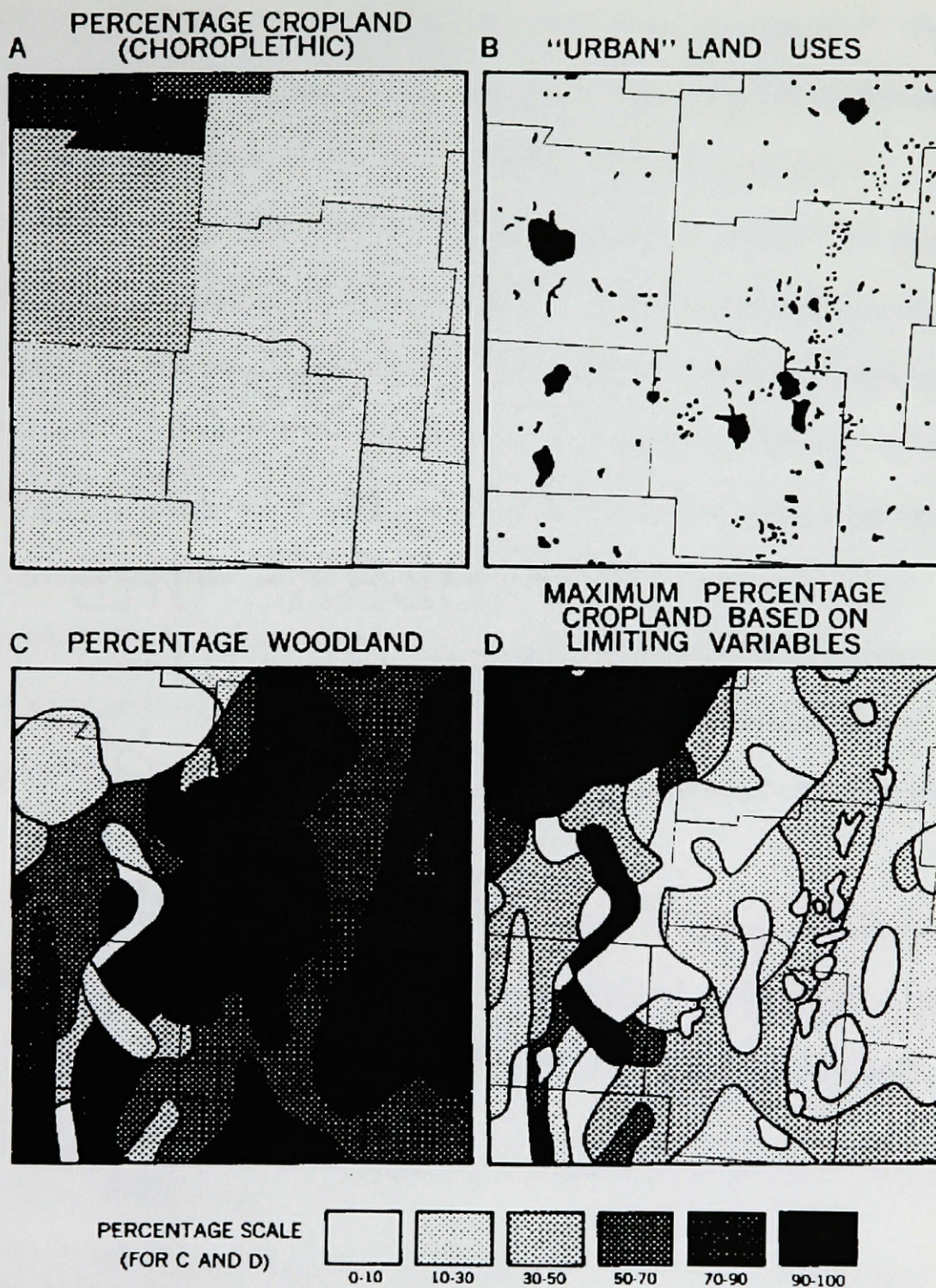


Fig1: How limiting variables are used in dasymetric mapping.
(Source: G. F. McCleary, "The Dasymetric Method in Thematic Cartography," Ph.D. diss., Univ. of Wisconsin, 1969, Figure 5.17.)

variations in spatial association with the phenomenon being mapped."²⁷ The application of the related variables to a dasymetric map cannot be explained so easily as the relationship of the limiting variables. What is required is a determination of the average spatial correlation between a variable (or a series of variables) and the phenomenon being mapped.²⁸ Based on the spatial correlation, the cartographer can use a regression method to derive a "predicted" distribution. In other words, the cartographer can use the linear correlation between a variable (or a series of variables) whose distribution is already known and the phenomenon being mapped to predict the distribution to be mapped.²⁹ Although related variables are more difficult to use properly in dasymetric mapping, they are very useful in helping the cartographer put some geographic sense into the bare statistics that are commonly gathered in political or administrative enumeration units.³⁰

Figure 2 shows a simple process of using related variables to predict a dasymetric surface; it deals with the same topic as Figure 1. The related variables used here include the type of surface configuration and the type of economic

²⁷A. H. Robinson et al., Elements of Cartography 6th ed (New York: John Wiley & Sons, 1995), 523.

²⁸G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (Ph.D. diss., University of Wisconsin, 1969), 185.

²⁹For detailed explanation of regression analysis, see A. H. Robinson et al., Elements of Cartography 6th ed (New York: John Wiley & Sons, 1995), 269-273.

³⁰A. H. Robinson et al., Elements of Cartography 6th ed (New York: John Wiley & Sons, 1995), 524.

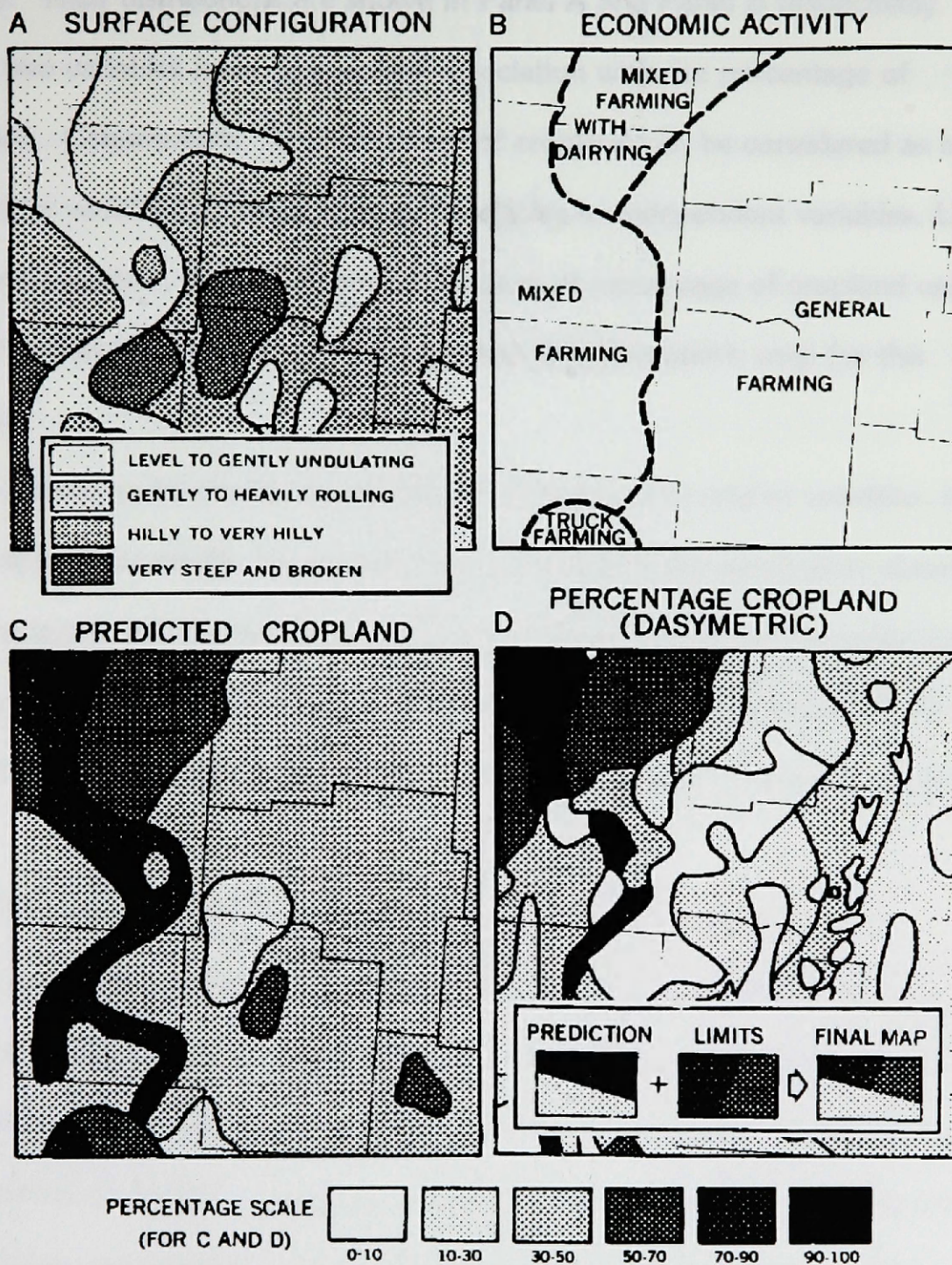


Fig2: How related variables are used in dasymetric mapping.
(Source: G. F. McCleary, "The Dasymetric Method in Thematic Cartography," Ph.D. diss., Univ. of Wisconsin, 1969, Figure 5.19.)

activity. Their distributions are shown in Panel A and Panel B respectively. These two variables have close spatial association with the percentage of cropland. Consequently, the percentage of cropland can be considered as an dependent variable and the two related variables as independent variables. Using a regression method, the "predicted" distribution of percentage of cropland can be derived (Panel C). Panel D in Figure 2 is the final dasymetric map for this example.

In summary, by combining the effects of limiting and related variables, the cartographer can modify the enumeration units so that the distribution shown on the map better reflects the actual distribution. When combining the influences of limiting and related variables, the cartographer may use any combination the methods mentioned above such as areal grouping, dividing, boundaries rounding, etc.

The internal adjustment method just described involves the most complicated methodology for the derivation of a dasymetric surface. On the one hand, since this method contains the most precision and organization in the compilation of dasymetric surface, it should be most amenable to computerization. The others hold much less promise. On the other hand, since many different kinds of data are currently collected for administrative or political enumeration units, this method will have potential use in properly representing these data on maps. Thus, the internal adjustment technique was chosen as the basis for developing automated dasymetric mapping.

The General Procedure of Dasymetric Mapping

It will be helpful to discuss the general procedure of dasymetric mapping first before dealing with the problems of developing automated dasymetric mapping. The general procedure for making a dasymetric map can be presented in five steps: (1) checking the original data, (2) analyzing the phenomenon to be mapped, (3) preparing a database, (4) defining the dasymetric pattern and (5) making the dasymetric map. This general procedure applies to all types of dasymetric maps.

Checking the Original Data

This step includes locating and verifying the original data and making several decisions regarding it. Most data collection enumeration units "are imposed arbitrarily onto spatial distributions for administrative or simply for data collection convenience".³¹ Thus, the cartographer should learn what kind of enumeration units were used in the original data collection and decide whether such units can adequately portray the actual distribution of the phenomenon being mapped. If the pattern of enumeration units largely duplicates the actual distribution of the phenomenon to be mapped, the choroplethic technique can be used, otherwise the dasymetric technique will be more proper. Moreover, if the dasymetric technique is chosen, the cartographer needs to decide which mapping

³¹I. Bracken, "Towards Improved Visualization of Socioeconomic Data," in Visualization in Geographic Information Systems, ed. H. M. Hearnshaw and D. J. Uniwin (Chichester: John Wiley & Sons, 1994), 77.

method should be used. Therefore, after examining the original data, the best dasymetric mapping method to represent the original data can then be selected.

A good example of this step might occur when building a dasymetric map of population density. When mapping population density for a suburban area, the cartographer may learn that census geographic areas do not portray the actual population density distribution well after checking them against the original census population data. Thus, the decision might be made that the proper mapping technique for this map would be dasymetric technique.

Analyzing the Phenomenon to Be Mapped

Except for the pure dasymetric technique, dasymetric mapping requires a great deal of additional information. To decide which kinds of additional information are needed, the cartographer must link the distribution of the phenomenon to be mapped to other related distributions. First, the cartographer identifies variables that influence the spatial distribution of the mapping phenomenon. Then, the spatial correspondences between those variables and the phenomenon to be mapped are analyzed. Finally, a conclusion about those variables' types (limiting or related),³² is drawn based on the analysis. This conclusion is necessary for choosing the correct method to derive useful information from the limiting and related variables and to help represent the distribution of the phenomenon the proper way.

³²See above, pp. 13-18.

This step helps the cartographer gather additional information about the distribution to be mapped at the proper level of detail. Also, this step helps the cartographer make a decision about the scale at which the final dasymetric map should be drawn. Therefore, this step actually is the process of identifying and gathering additional data required for dasymetric mapping. It is important because "without spending some effort ensuring that various data sets are not only relevant but also reliable, we run the risk of fooling ourselves."³³

Preparing a Database

Much of the additional information required for dasymetric mapping may come in different formats, media, or scales. Unfortunately, many of those may not be computer compatible. Some may occur as printed manuscripts; others may be only images such as those present on Micro Fiche. Before these sources can be used together to define a dasymetric pattern, they need to be reprocessed. Reprocessing includes data format conversion, medium conversion, scale conversion, image interpolation, etc. This step makes all data sets compatible with one another and suitable for use in dasymetric mapping.

Defining the Dasymetric Pattern

Once all necessary data are at hand, the cartographer uses them to define the dasymetric surface with uniform areas separated by zones or boundaries of

³³J. Star and J. Estes, Geographic Information Systems: An Introduction (Englewood Cliffs, N.J.: Prentice Hall, 1990), 25.

abrupt change by using the methods discussed above. Here a conscious effort is made to separate disparate areas, to group together areas of similar statistical values, and to reveal on the map the pattern of variation which is otherwise hidden by administrative, political, or other similar unit areas.³⁴

This step involves the most sophisticated work in dasymetric mapping. It requires the cartographer to make some knowledgeable but subjective decisions about uniform areas and zones or boundaries of abrupt change. These decisions show how well the cartographer replaces the arbitrary enumeration unit boundaries with boundaries more reflective of the distribution being mapped. For example, when making a population density map, the cartographer needs to locate boundaries for different population densities. Therefore, this step alters the original data collection units to get a proper base for the final dasymetric map. At the same time, when the original areal collection units are altered, their attribute data also need to be manipulated to fit the new base map. Thus, two types of spatial analyses are involved in this step. One is based on the geographic data, and the other is based on the attribute data. Therefore, defining the dasymetric pattern is the most time consuming step in dasymetric mapping.

Making the Dasymetric Map

This step is similar to choropleth technique. It includes general thematic mapping procedures such as grouping attribute values into different class intervals,

³⁴G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (Ph.D diss., University of Wisconsin, 1969), 10.

choosing the appropriate symbols or tones to represent each class, adding a proper map title, map legend, and other necessary components for the final thematic map.

Current Situation of Automated Dasymetric Mapping

Unlike choroplethic mapping, an automated software package is unavailable for dasymetric mapping. This has tended to hinder the use of this technique during the last decade or so. Only a few journal articles have mentioned this problem.³⁵ None has carefully discussed it.

Since dasymetric mapping is by all counts a useful traditional thematic mapping technique, it should be used whenever it is deemed to be most appropriate. To popularize its use, every effort should be made to incorporate it among the various automated thematic mapping methods now in use. To accomplish this, the first thing that needs to be done is to simplify the technique and make the data analysis and manipulation involved in its compilation easier and faster. These tasks will be dealt with in the following chapters.

³⁵See Chapter One pp.4-5.

Chapter Three

AUTOMATED DASYMETRIC MAPPING

Dasymetric maps and the methodology of traditional dasymetric mapping were described in the previous chapters. These chapters also revealed that although it might be possible to create a dasymetric map with a GIS, no single piece of software has been yet designed explicitly for that purpose. Still, by coincidence, many of the tools necessary for creating dasymetric maps are found in GIS packages.

The present chapter will discuss how the dasymetric technique might be adapted to available GIS and mapping software packages. First, it will be necessary to define what a GIS is, and briefly discuss some of the concepts, components, and operations involved before applying them to dasymetric mapping. Secondly, the possibilities of automated dasymetric mapping will be described, and, finally, a design for adapting current GIS packages to effect the dasymetric mapping will be specified.

Geographic Information Systems and the Dasymetric Mapping Technique

A GIS is defined as "a decision support system involving the integration of

spatially referenced data in a problem solving environment."¹ In other words, a GIS provides the tools for working with spatially-referenced data that we have always needed in order to truly synthesize the disparate sources of spatial information.² There are four major components that a GIS should contain: data acquisition, data management, manipulation and analysis, and product generation. The main operations of these four components are described in the following sections.

Data Acquisition

Data acquisition is the process of identifying and gathering the data needed for a project. The operation is mainly concerned with entering data into the system. It includes manual digitizing, scanning, and keyboard entry of data which exists in hard copy format. It also includes importing information from other database systems which exist in electronic format.

The data acquisition element of a GIS, particularly the digitizing and data importation features, are important for the automation of dasymetric mapping. As discussed in previous chapters, dasymetric mapping requires vast quantities of information.

The first three steps of making a dasymetric map are primarily related to building either geographic or attribute databases. Constructing these databases is

¹D. J. Cowen, "GIS versus CAD versus DBMS: what are the differences?" Photogrammetric Engineering & Remote Sensing 54 (1988): 1555.

²Ibid.

a particularly tedious, yet essential, task. With the help of a GIS, however, the job is greatly simplified. For example, the data required for a dasymetric map may exist in several different formats—some may exist as printed materials (maps or tables), others may be images (micro fiche), others still may be in electronic format (Census data, DLG files, etc.). Creating these types of databases by employing the procedures of traditional dasymetric mapping used to be a very difficult, if not impossible job. But with the help of a GIS, converting the data from many of these sources into a computer compatible format is relatively easy.

Data Management

Data management is the element which makes databases available to the users of GISs. An assortment of GIS tools provides the cartographer with simple and efficient access to either geographic or attribute databases. Though far from exhausting the list of possible uses, the facilities made available through GIS include storage, editing, merging, deletion, selection, and retrieval of information. Without the element of data management and its various tools, neither spatial nor attribute analysis would be possible.

Together the elements of data acquisition and data management not only make it possible to obtain the information necessary to conduct dasymetric mapping; but they allow for it to be manipulated in many of the ways necessary for carrying out the various steps involved in the technique. With these elements the cartographer can easily access and manage the extensive databases which are necessary.

Manipulation and Analysis

Data manipulation and analysis in a spatial context comprise the core elements of a GIS. The elements include "the whole spectrum of techniques available for the transformation of the digital model by mathematical means."³ Data manipulation and analysis are so central to a GIS that a common mistake is to say that a GIS consists of nothing else.

These two elements include the operations needed to analyze and manipulate both the geographic and the attribute databases. These operations are shown in Table 1;⁴ they provide the user with a variety of tools; including statistical tools, database tools, and spatial analytical tools. By performing these operations, the user can derive new and valuable information for different applications from the existing database. It should be pointed out that some of the operations, such as data structure conversion and statistical analysis, are common among database management systems (DBMS) and computer mapping systems. Other operations, such as spatial operations and measurement, are unique capabilities of GISs. It is these unique capabilities that differentiate the GIS from other database management systems and computer mapping systems.

The unique operations of a GIS may possibly facilitate dasymetric mapping. When transforming the enumeration boundaries into the dasymetric boundaries,

³D. Martin, Geographic information systems and their socioeconomic applications (London: Routledge, 1991), 51.

⁴J. Star and J. Estes, Geographic Information Systems: An Introduction (Englewood Cliffs, N.J.: Prentice Hall, 1990), 144.

several spatial operations are involved such as polygon overlay, areal subdivision, aggregation, boundary rounding, etc. These spatial operations can be

Table 1.–The Main Operations of GIS

Reclassification and Aggregation
Geometric Operations
Rotation, Translation, and Scaling
Rectification and Registration
Data Structure Conversion
Spatial Operations
Overlay operation
Neighborhood operation
Centroid determination
Measurement
Distance
Direction
Connectivity
Statistical Analysis
Descriptive statistics
Regression, Correlation, and Cross-tabulation
Modeling

implemented by various GIS functions. The geometric operations will help the cartographer register all of the required data from various sources together. The statistical analysis, reclassification and data structure conversion functions will provide powerful tools for the non-spatial attribute data analyses involved in dasymetric mapping.

Product Generation

Product generation is the element responsible for creating the final output from a GIS. The final products are generally of two types: soft copy (images) and

hard copy (printed materials). The hard copy is used mostly for final display. In addition to display, the soft copy has the capability of taking the output of an analytic process and placing it back into the geographic database for further analysis.⁵ This capability is extremely important because it extracts useful information from the original data for the purpose of further analysis.

Similar to the other functions, product generation has the potential for being useful in automated dasymetric mapping. As mentioned in earlier chapters, the distributions of limiting and/or related variables are used in dasymetric mapping.⁶ Thus, the cartographer needs to analyze the distributions of these variables and their relationships to the phenomenon being mapped first and then use the results for the purpose of defining the dasymetric pattern. This process used to be very time-consuming. It promises to become easier and faster once a GIS is used for dasymetric mapping.

Raster and Vector GIS

There are two fundamental approaches to the representation of geographic information: the raster structure and the vector structure. In the raster structure, the spatial units are comprised of cells (usually square or rectangular in shape). The location of geographic objects is defined by the row and column position of the cells. In the vector structure, the spatial units are points, lines, and polygons.

⁵Ibid., 27.

⁶See Chapter two.

The location of the spatial objects is referenced by a coordinate system. These two different structures have their advantages and disadvantages (see Table 2).^{7 8} Some GISs are entirely raster-based such as IDRISI; others are vector-based, for example, Atlas GIS. There are some GISs which work with both raster and vector data structures. The UNIX version of ARC/INFO is an example of this; it not only has the capabilities of working with both data structures, but the capability of converting one structure into the other.

Neither the raster nor the vector structure is clearly superior as the basis for a GIS. The choice of one over the other will depend upon the type of data to start with, the manner of analysis desired, and the character of the output needed. If the geographic information of interest primarily involves spatial variability of a phenomenon, the raster structure is better. But, if the spatial information of interest is related to areal features and boundaries, then the vector representation will work well. In order to implement automated dasymetric maps, both of these types of data structures are needed. This issue will be discussed more in the following section.

The Possibilities of Automated Dasymetric Mapping

The question--"is automated dasymetric mapping possible?" should be

⁷S. Aronoff, Geographic Information Systems: A Management Perspective (Ottawa: WDL Publications, 1991, reprint, 1995), 166.

⁸P. A. Burrough, Principles of Geographical Information Systems for Land Resources Assessment (Oxford: Clarendon Press, 1986, reprint, 1987), 36.

decisively answered before attempting to adapt the traditional dasymetric

Table 2.—Comparison of Raster and Vector Structures

RASTER	VECTOR
Advantages:	Advantages:
<ol style="list-style-type: none"> 1. It is a simple data structure. 2. Overlay operations are easily and efficiently implemented. 3. High spatial variability is efficiently represented. 4. Simulation is easy because each spatial unit has the same size and shape. 5. The technology is cheap and is being energetically developed. 	<ol style="list-style-type: none"> 1. It provides a more compact data structure. 2. Topology can be completely described with network linkages. 3. It is better in supporting graphics that closely approximate hand-drawn maps. 4. Retrieval, updating and generalization of graphics and attributes are possible.
Disadvantages:	Disadvantages:
<ol style="list-style-type: none"> 1. It is less compact. Data compression technique can often overcome this problem. 2. Topological relationships are more difficult to represent. 3. The output of graphics is less aesthetically pleasing. This can be overcome by using a very large number of cells, but may result in unacceptably large files. 	<ol style="list-style-type: none"> 1. It is a more complex data structure than a simple raster. 2. Overlay operations are more difficult to implement. 3. The representation of high spatial variability is inefficient. 4. Manipulation and enhancement of digital images can not be efficiently done in the vector domain.

technique to available GIS and mapping software packages. According to the discussion in previous chapters, it is obvious that dasymetric mapping is not a

simple process. It includes very complicated geographic and attribute data manipulation and analysis. Moreover, most methods of traditional dasymetric mapping require that the cartographer make numerous subjective decisions regarding both the manipulation of the data and the positioning of the dasymetric boundaries. Therefore, automated dasymetric mapping is not just a mapping process, rather it is also a decision making process involving the manipulation and analysis of both spatial and non-spatial attribute data. Although the dasymetric mapping is necessarily complex, still it is worthwhile, since the technique allows the cartographer to begin with a limited statistical data and end up with a map that displays a detailed statistical surface.

Without question, a GIS, as described in the previous section, is a good choice to perform the complicated geographic and non-spatial attribute data manipulation and analysis involved in dasymetric mapping. A GIS will help automate the traditional dasymetric technique mainly in three aspects: (1) integrating all of the required data; (2) manipulating and analyzing the data; and (3) supporting the cartographer during the decision making process. These three aspects will be described respectively in the sections which follow.

Data Integration

Data requirement is an important issue for dasymetric mapping. With the use of a GIS, huge amounts of dissimilar geographic data can be collected, stored and manipulated faster and easier than ever before. The capability which differentiates a GIS from database management systems on one hand and

computer-aided mapping systems on the other is that the GIS is able to link a complex geographic database with a complex attribute database and to manipulate the interrelationships between them.⁹ Therefore, the capability of data integration of a GIS should greatly benefit dasymetric mapping. Using a GIS, the cartographer can peruse existing data sources to select the best possible supporting information for creating a dasymetric map.

Moreover, as discussed above, some GISs have the capability of working with both raster and vector data structures. This capability is very useful for automated dasymetric mapping. In order to implement dasymetric mapping, both data structures are needed. On the one hand, the transformations of boundaries are the main task involved in dasymetric mapping. Since vectors can follow lines very closely, maps produced from vector-based mapping systems are "capable of greater resolution and accuracy."¹⁰ Thus, a vector-based GIS will be better suited to analyze the data and to generate the final product. On the other hand, many geographic data, which are required by dasymetric mapping, are gathered and stored in gridded formats, for example digital elevation models (DEM), satellite images, etc. Therefore, a raster-based GIS will play an important role in automated dasymetric mapping. Only with the use of a GIS, can those data with

⁹R. Flowerdew, "Spatial data integration," in Geographic Information System: Principles and Applications, ed. D. J. Maguire, M. Goodchild and D. W. Rhind (England: Longman Scientific & Technical, 1991), 385.

¹⁰K. C. Clarke, Analytical and Computer Cartography 2d ed (Englewood Cliffs, N.J.: Prentice Hall, 1995), 135.

different structures be integrated for the purpose of dasymetric mapping.

Data Manipulation and Analysis

Besides requiring copious amounts of information over and above the original data set, substantial analysis is involved in dasymetric mapping in order to define the uniform areas and zones of abrupt change (discussed in Chapter Two). Therefore, automated dasymetric mapping not only needs the data classification and symbolization tools which are the focus of most computer cartography systems, but also requires the ability to conduct spatial (geographic) and non-spatial attribute data analysis.

Geographic data are referenced to locations on the earth's surface by using a standard system of coordinates. These data are complicated by the fact that they must include information not only about the position of geographic features, but also about possible topological connections and an assortment of attribute labels which name or describe the objects recorded.¹¹ All geographic data can be reduced to three basic topological concepts—points, lines, and areas. These are ordinarily stored in the geographic data base as topologically referenced points, chains, and polygons.

Non-spatial data are those properties of a spatial entity such as population counts for an area, a name for a line, etc. One of the cartographer's tasks while making a traditional dasymetric map is to link non-spatial attribute data to the

¹¹P. A. Burrough. Principles of Geographic Information Systems for Land Resources Assessment (Oxford: Clarendon Press, 1987), 13.

geographic data and to correctly portray them on the maps with a minimum of information loss. This used to be a very tedious and difficult job because spatial and non-spatial data were collected and stored separately. But, with the help of a GIS, this job should be much easier.

It has been pointed out above that one of the main functions of GIS is data manipulation and analysis. A GIS can organize spatial (geographic) and non-spatial attribute data together in one computer environment and allow for complete data query and analysis.¹² Thus, it is possible to use the GIS's powerful analytical functions to help the cartographer perform all sorts of data analyses to derive a dasymetric representation.

According to the methodology and general procedure of dasymetric mapping, transforming enumeration units into dasymetric zones based on related distributions is actually a polygon overlay process. Performing polygon overlay manually, even for a small area, is very complicated and time-consuming. Fortunately, polygon overlay is one of the key operations in GIS analysis. The computer has the ability to overlay the polygons of two or more separate coverages and to actually fuse them together. In the process the parent polygons of the original coverages are disaggregated into smaller polygons which retain the combined attributes of the parents. The more versatile vector GISs have an assortment of tools which allow statistical data to either be copied or proportioned

¹²Nancy Von Meyer, "The Definition and Principles of GIS." Public Works, 124 (February, 1993): 44.

in one way, or another to match the new polygons in a logical manner. Using a GIS to access additional databases and to perform polygon disaggregational analysis has the potential of greatly simplifying the dasymetric mapping technique.

One of the basic questions that can be investigated using GIS relates to the pattern (e.g. what is the pattern of population density distribution?).¹³ It is likely that the cartographer will face this kind of question in dasymetric mapping. When the cartographer tries to define a dasymetric surface, the intention is to reveal a distribution pattern of the phenomenon being mapped which is "more realistically and more truly geographical than by using choroplethic or isarithmic methods."¹⁴ Thus, a GIS is able to define a more detailed spatial distribution pattern for the purpose of automated dasymetric mapping.

Supporting Decision Making

It is clear that process of defining the dasymetric pattern requires many careful and objective decisions.¹⁵ When possible, these decisions should be made by the cartographer, not by the computer. In this context the GIS becomes merely a tool to help the cartographer make the decisions which are necessary for creating the map. That is to say, automated dasymetric mapping requires

¹³D. J. Maguire, "An Overview and Definition of GIS," in Geographic Information System: Principles and Applications, ed. D. J. Maguire, M. Goodchild and D. W. Rhind (England: Longman Scientific & Technical, 1991), 16.

¹⁴G. F. McCleary, "The Dasymetric Method in Thematic Cartography" (Ph.D diss., University of Wisconsin, 1969), 86.

¹⁵*Ibid.*, 26.

"liveware". "Liveware" refers to the cartographer; and it is the cartographer who ultimately must define uniform areas and zones of abrupt change that are required by the technique. As it turns out, one of the most significant components of a GIS is the "liveware"--"the people responsible for designing, implementing and using GIS. Without properly trained personnel with the vision and commitment to a project little will be achieved."¹⁶ Thus, the same requirement that makes it possible to use GIS in many other contexts has the potential of becoming a valuable tool for the purpose of automated dasymetric mapping.

In summary, cartographic presentation is a component of GIS; it is used to present the result of geographic analysis. At the same time, the GIS, as a powerful tool, will benefit cartographers when they make different kinds of maps. Automated dasymetric mapping will provide an excellent illustration of how GIS helps cartographers with map making. But how will automated dasymetric mapping be implemented with the help of a GIS? This will be discussed in the remainder of this chapter.

A Design for Automated Dasymetric Mapping Using GIS

It was already discussed in Chapter Two that the general procedure of making a dasymetric map includes five steps: checking the original data, analyzing the phenomenon to be mapped, preparing a data base, defining the dasymetric

¹⁶D. J. Maguire, "An Overview and Definition of GIS," in Geographic Information System: Principles and Applications, ed. D. J. Maguire, M. Goodchild and D. W. Rhind (England: Longman Scientific & Technical, 1991), 16.

pattern and making the dasymetric map. When a GIS is used to approach automated dasymetric mapping, these five steps will be performed using different GIS elements. The first three steps can be approached by data acquisition and data management. The fourth step, the most important one concerning dasymetric mapping, is actually a process of spatial and non-spatial attribute data manipulation and analysis. Finally, the dasymetric map will be produced by the product generation function of a GIS.

The Table 3 gives a design which shows how dasymetric maps might be created using a GIS. This design includes six steps, and at every step there are several tasks involved. Generally, automated dasymetric mapping can be undertaken by completing all six steps using a GIS, although the not all of tasks listed under each step may be necessary depending upon the particular problems involved.

Table 3.—A Design for Automated Dasymetric Mapping

Step 1: Problem Specification

Objectives:

Select a proper type to represent the mapping phenomenon, and make decisions about the scale of the final dasymetric map, as well as additional information.

Tasks:

- a) The original data checking
- b) The mapping phenomenon analysis

Step 2: Data Acquisition

Objectives:

Gather all required data, design the database and build the database.

Tasks:

- a) The additional data identification and acquisition
- b) Defining the geographic data layers
- c) Data medium conversion
- d) Data format conversion
- e) Data scale conversion
- f) Defining database structure
- g) Building the map layers
- h) Building the database

Step 3: Spatial Analysis Based on the Spatial Data

Objective:

Manipulate the base map to define a dasymetric surface.

Tasks:

- a) Polygon overlay
- b) Areal subdivision
- c) Areal elimination

Step 4: Attribute Data Analysis

Objectives:

Manipulate attribute data and merge them with the adjusted base map

Tasks:

- a) Merging attribute data with the adjusted base map
- b) Calculating the statistics

Step 5: Spatial Analysis Based on the Attribute Data

Objective:

Define a thematic overlay.

Tasks:

- a) Making the decision concerning uniform areas

b) Areal aggregation

Step 6: Making the Dasymetric Map

Objective:

Present the result.

Task:

Constructing the thematic map.

It should be pointed out that although automated dasymetric mapping can be undertaken with a GIS, the cartographer still must play a very important role in the process. There are several tasks involved in automated dasymetric mapping that have to be accomplished by the cartographer. These are described in the next section.

The Role of the Cartographer

It has been mentioned above that "a cadre of trained, educated, motivated, and dedicated people is crucial to a successful GIS program."¹⁷ This "liveware" is a particularly important element of automated dasymetric mapping. There are two distinct operations involved in the process of automated dasymetric mapping. One is performed by the computer as previously discussed, and the other is done by the cartographer whose performance can not be replaced by any of the functions of the computer.

Generally, in map making, the cartographer's task is to devise the very best

¹⁷N. Von Meyer, "The Definition and Principles of GIS," Public Works, 124 (February, 1993): 44.

approximation to an 'ideal' transformation involving a minimum of information loss.¹⁸ The role of the cartographer in automated dasymetric mapping is to act mainly as a decision-maker. There are many tasks concerning decision making in automated dasymetric mapping. "Almost every step requires the cartographer to make some knowledgeable, but subjective, decision."¹⁹ These decisions are all related to the accuracy of the dasymetric map. The cartographer has to use his or her own knowledge and familiarity with the mapping theme and mapping area to make these decisions. The decisions deal with many different aspects of dasymetric mapping; they are required at each different step of the process.

Some typical questions requiring decisions are:

- 1) What kind of dasymetric map should be used to portray the phenomenon being mapped (Step 1)?
- 2) What scale should be chosen for the final dasymetric map (Step 1)?
- 3) How much additional information is needed (Step 1)?
- 4) How should this additional information be used to define the dasymetric pattern (Step 2)?
- 5) Where are uniform areas and zones of abrupt change (Step 5)?

It is these kinds of questions and decisions that make dasymetric maps different from choropleth maps. Without them, a dasymetric representation is impossible.

¹⁸D. Martin, Geographic Information Systems and Their Socioeconomic Applications (London: Routledge, 1991), 29.

¹⁹A. H. Robinson et al, Elements of Cartography 6th ed (New York: John Wiley & Sons, 1995), 525.

All of the tasks relating to decision-making have to be performed by the cartographer.

Most importantly, the cartographer's role in automated dasymetric mapping makes the method different from automated choroplethic mapping or automated isoplethic mapping. Using a mapping software package, even a non-cartographer with little or no cartographic training can make a choropleth map very quickly. But this is impossible while making a dasymetric map. Without any cartographic training, it would be impossible for anyone to make conscious effort to define areas of uniform statistical value separated by zones of abrupt change. As a result, the cartographer's role and the communications between himself and the computer are indispensable in automated dasymetric mapping.

Chapter Four

AN EXAMPLE OF AUTOMATED DASYMETRIC MAPPING

In Chapter Three, a design for automated dasymetric mapping using GIS software packages was outlined. But the question of how this design can be implemented still remains. This chapter will use the Missoula urban area population density as an example to demonstrate how the design can be implemented. The GIS packages used in this study are IDRISI and Atlas GIS. IDRISI is a raster-based geographic information system and image processing system; Atlas GIS is a vector-based desktop geographic information system. The demonstration will follow the steps that are listed in the design.¹ Following the demonstration, some of the possible errors and merits of automated dasymetric mapping will be briefly discussed.

Making a Dasymetric Map Using GIS

Step 1: Problem Specification

Problem specification is a basic but important step for dasymetric mapping. The objective of this step is to analyze the phenomenon to be mapped in order to select a proper dasymetric type to best represent the original data and then to

¹See Table 3 in Chapter Three.

decide what kinds of additional information are needed to accomplish the mapping. The tasks involved in this step are: (1) checking the original data, and (2) analyzing the phenomenon (in this case the distribution of population).

Checking the Original Data

The data for the population densities throughout the Missoula urban area are found in the 1990 Census of Population data.² Census population data are collected for census geographic areas such as census tracts, block groups, blocks, etc. In an urban area, a census block might be an actual city block; in rural areas, blocks may be much larger areas bounded by rivers, railroads, shorelines, political boundaries, or other features that form the logical boundaries for polygons.³

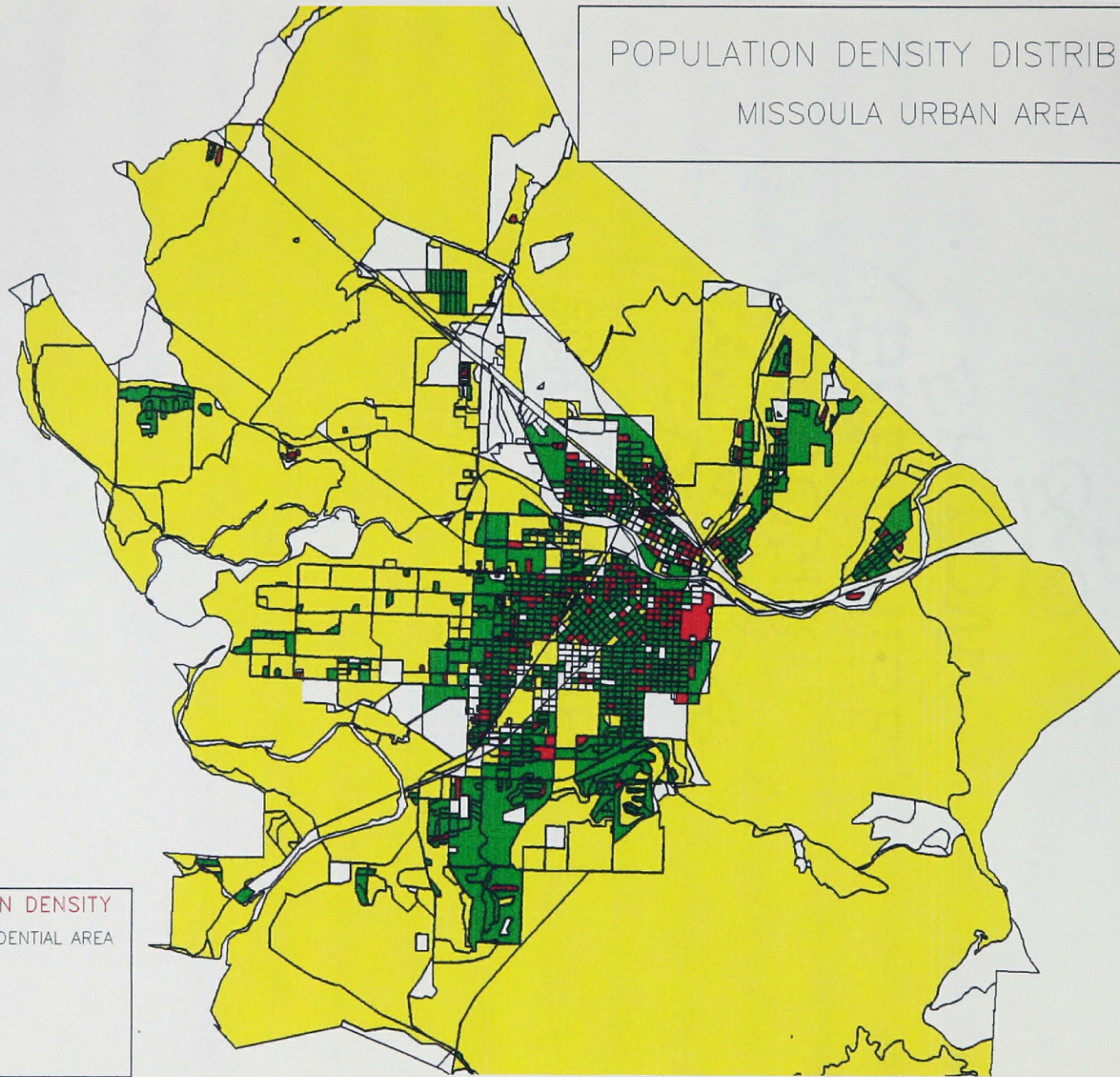
It is a relatively simple process to build a choropleth map based on census block data. Map 1 was constructed using the thematic mapping operations of Atlas GIS. It is a quantitative choropleth map which employs a simple ordinal classification of the data into a frequency distribution. For all blocks in Missoula urban area, the average population density is about 5,000 persons per square mile, and the standard deviation is approximately 3,000 persons per square mile. For simplicity, the data were classified into four categories (Table 4).

²The U.S. Bureau of the Census, Census of Population and Housing, 1990, P.L. 94-171 (a CD-ROM).

³W. E. Huxhold, An Introduction to Urban Geographic Information System (N.Y.: Oxford University Press, 1991), 159.

MAP1

POPULATION DENSITY DISTRIBUTION MISSOULA URBAN AREA



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Table 4.--The Categories for the Classification in Map 1

Non Residential:	no population
Low:	less than 2,000 persons/square mile
Medium:	2,000 --- 8,000 persons/square mile
High:	more than 8,000 persons/square mile

The problem with choropleth maps similar to Map 1 is that at best, they give only an inferior representation of the actual distribution of population. The areas mapped as "Non Residential" are accurate representations of the distribution of people, and the smallest blocks are not unsatisfactory representations either. But, the largest blocks are very inaccurate representations. For example, two of the largest blocks are those located southeast of the city in the areas of Mount Sentinel and Mount Dean Stone. It is likely that the few people who reside in these areas probably occupy less than one or two percent of the space involved. Of course, if the areas could be adjusted to more accurately fit the population distributions as would be the case with a dasymetric map, then much of the problem could be overcome. The following paragraphs will trace the steps involved in converting the choropleth representation in Map 1 into a dasymetric map using the choropleth dasymetric mapping method.

Population Density Distribution Analysis

As discussed in previous chapters, deriving a dasymetric representation requires pursuing several steps involving spatial analysis. With regard to the current example, these steps include searching a series of variables which influence the distribution of the phenomenon to be mapped and analyzing the

relationships between these variables and the phenomenon to be mapped.

The distribution of population density is closely related to land cover and land use distributions. For the following land-cover and land-use types: water, forest land, barren land, agricultural and range land use, the population density will be zero. For public land uses, such as parks and schools, as well as commercial, service, and transportation land uses in the urban buildup areas, population density will be zero also. Consequently, these different land-cover and land-use types can be used as limiting variables for dasymetric mapping.

As for a related variable, slope would be a good choice. Most residential houses in the Missoula urban area have been built on areas with slopes less than 10%. If slopes are greater than 10% but less than 25%, a special building permit is required by the city zoning regulation. If slopes are greater than 25%, it is very difficult to obtain a permit. If slopes are greater than 35%, it is impossible to obtain a building permit.⁴ Accordingly, the population density can be "predicted" by the relationship between slope and residential housing.

Actually, for mapping population densities based on census blocks located within the heavily built-up area of Missoula, a consideration of slope would not seem to be required since the census blocks are small enough to differentiate population density changes with different slope distributions. However, for suburban and rural areas, slope distributions may help locate inhabited areas.

⁴The information regarding slopes and residential houses comes from an interview with Dr. Evan Denney, the Department of Geography, the University of Montana, August 1995.

Therefore, this study will use slope as a related variable. By superimposing the slope map on the census map and counting the number of housing units in the areas with different slopes, the relationship between residential housing units and slope in Missoula urban area could be estimated with a reasonable degree of accuracy. The result is given in Table 5.

Table 5.--Relationship between Residential Housing Units and Slope in Missoula Urban Area

Slope (Percent)	Percentage of Total Housing Units
Less than 10	80
Between 10 and 25	15
Between 25 and 35	5
Greater than 35	0

Step 2: Data Acquisition

The objective of this step is to gather all of the required data and then design and build the database. The tasks involved in this example are: defining the geographic layers, data identification and collection, defining the data structure, data conversion, building the map layers and the database, etc. These are described as follows.

Defining the Geographic Layers

Several layers are needed in addition to census data; these include the data for land cover, land use, slopes, and water bodies. A summary of all of the layers, their classes, and their sources is listed in Table 6.

Table 6.—The Geographic Layers Defining

Layer	Class	Source
1. Block areas	Polygon	Tiger/Boundary files ⁵
2. Urban buildup area	Polygon	Missoula County land cover types image ⁶
3. Public land use	Polygon	Aerial photographs, Topographic sheets, City Bike Map, etc.
4. Rivers and lakes	Polygon	Tiger/Boundary files
5. Slopes	Polygon	DEM
6. Highway	Line	Tiger/Line Files ⁷
7. Road	Line	Tiger/Line Files
8. Railroad	Line	Tiger/Line Files

Data Identification and Collection

All eight layers listed in Table 6 use the vector structure because, as discussed above, analysis with a vector-based GIS will produce a dasymetric map of superior quality. By their uses in dasymetric mapping, these layers and their associated attribute variables, can be divided into three groups: (1) the original data (associated with the first, sixth, seventh and eighth layers); (2) limiting variables (the second, third and fourth layers); and (3) related variable (the fifth layer). These groups are briefly described in the following paragraphs.

⁵TIGER (Topologically Integrated Geographic Encoding and Referencing) system is a geocoding system developed by the U.S. Bureau of the Census for the 1990 Census. Objects in this system include points (nodes), lines (segments), and areas (blocks, census tracts, or enumeration districts). Tiger/Boundary files are digital extracts from the TIGER system. The files contain the information of census geographic areas such as census blocks, block groups, census tracts.

⁶This image was derived from Landsat TM images and provided by Missoula County Office of Planning and Program Development.

⁷Tiger/Line Files are digital extracts from the TIGER system. The files contain map feature information such as roads, rivers, railroads.

The original data include the block areas, highways, roads and railroads.

The block areas consist of the census blocks. Since the population densities for city blocks are the original data for this study, it is appropriate that the boundaries of these blocks would comprise the base map for this project. The blocks are derived from the Tiger/Boundary files produced by the Census Bureau.⁸

Moreover, the lines (including roads, highways, and railroads) are also extracted from the Tiger/Boundary files as the additional information for this project.

The limiting variables include the urban buildup area, public land uses, and rivers and lakes. The urban buildup area is extracted from the image of Missoula County Land Cover Types which is a classified Landsat TM image. Before being integrated into the database, it needs to be converted from raster mode into vector mode. Public land use is also used as a limiting variable in this study. Since the population densities will be zero for several types of public land uses including schools, parks, etc, all areas defined as public land uses according to the areal photographs, topographic sheets, and other reference maps are needed to be integrated into one layer. Similarly, the water bodies (including rivers and lakes), which have been extracted from the Tiger/Line files, also need to be integrated into one layer.

The related variable used in this study is the slope. The slope information is computed from the digital elevation models. Similar to the urban buildup area, the slope image needs to be converted into the vector mode before being

⁸See above Footnote No. 5.

integrated into the database.

An assumption is involved concerning all of the conversions (raster to vector) mentioned above, Since resolution for LANDSAT TM image is 30 by 30 meters and the minimum length must be three pixels or 90 meters on the ground to recognize areas with consistency, the information is discarded when it represents an area less than 1,000 square meters to reduce possible errors and avoid unnecessary details. Similarly, all polygons smaller than 1,000 square meters are discarded.

Building the Map Layers and Database

Through the implementation of the previous step (data identification and collection), all data required by this study are defined and gathered. Once this has been accomplished, the map layers and database can be built. For this project, the following tasks are accomplished for building the map layers and the database:

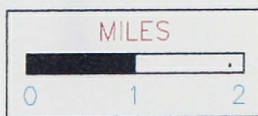
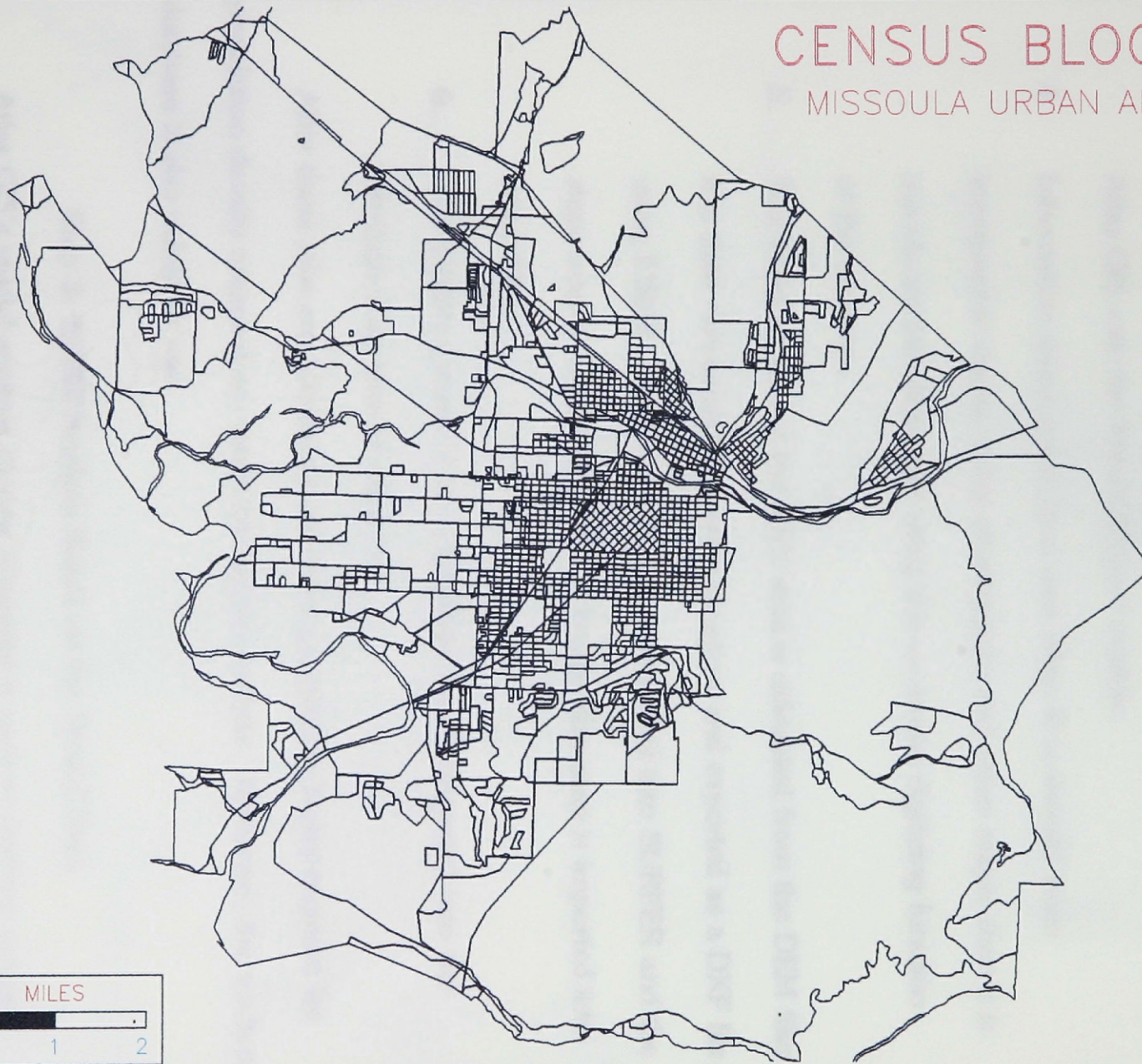
1. The base map (Map 2) is extracted from Tiger/Boundary files and imported into Atlas GIS using the TGRBDY (Tiger Boundary Translation program) and the Import/Export module of Atlas GIS.⁹
2. Similar to the previous step, all water bodies including rivers and lakes and all line information such as highways, roads and railroads are extracted and imported into Atlas GIS. They are stored as individual layers listed in Table 6.

⁹Ibid.

MAP2

CENSUS BLOCKS

MISSOULA URBAN AREA



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3. The urban buildup area (Map 3) is derived from the classified image of Missoula County Land Cover Types, and converted from the raster format to vector format using IDRISI. It is then imported into Atlas GIS with the Import/Export module.
4. Information about public land uses (Map 4) is derived from topographic sheets, aerial photographs and other maps; then it is introduced into Atlas GIS using the on screen digitizing function of the program.
5. The slope surface of the study area is calculated from the DEM files. It is then converted into vector structure and exported as a DXF file using IDRISI. Next, the DXF file is imported into SURFER and the slope map is created (Map 5).¹⁰ Finally, this map is imported into Atlas GIS.
6. The 1990's Census block population data is imported into the attribute data base of Atlas GIS.

After these jobs are completed, all of the geographic layers required for population density mapping are ready for further analysis. Moreover, the attribute database is also ready for use.

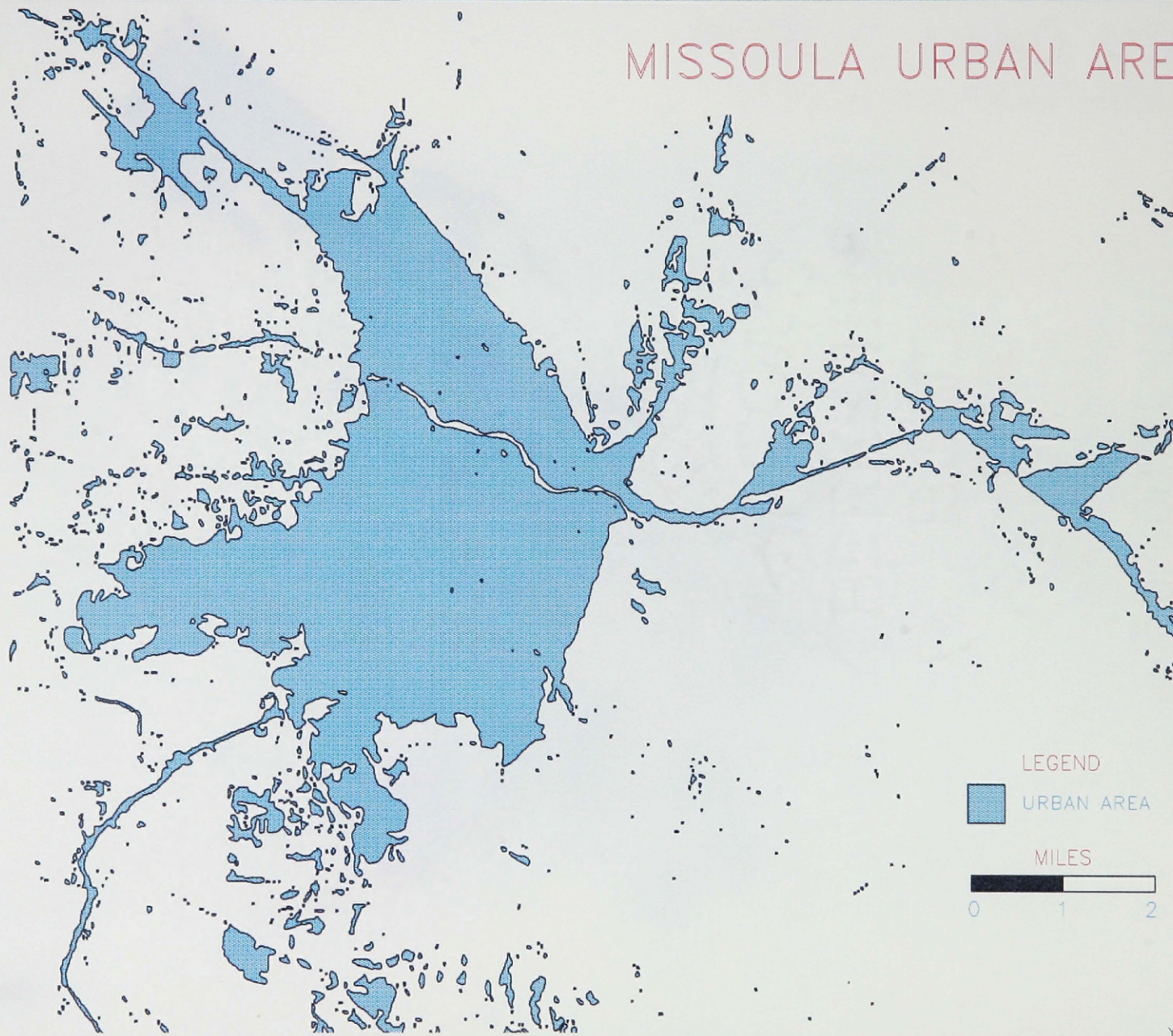
Step 3: Spatial Analysis Based on the Spatial Data

Atlas GIS's spatial analysis module (**Operate**) is used to perform polygon

¹⁰SURFER is a mapping software package designed to create full-color contour and 3D surface maps from and X, Y, Z data set.

MAP3

MISSOULA URBAN AREA



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MAP4

PUBLIC LAND USE

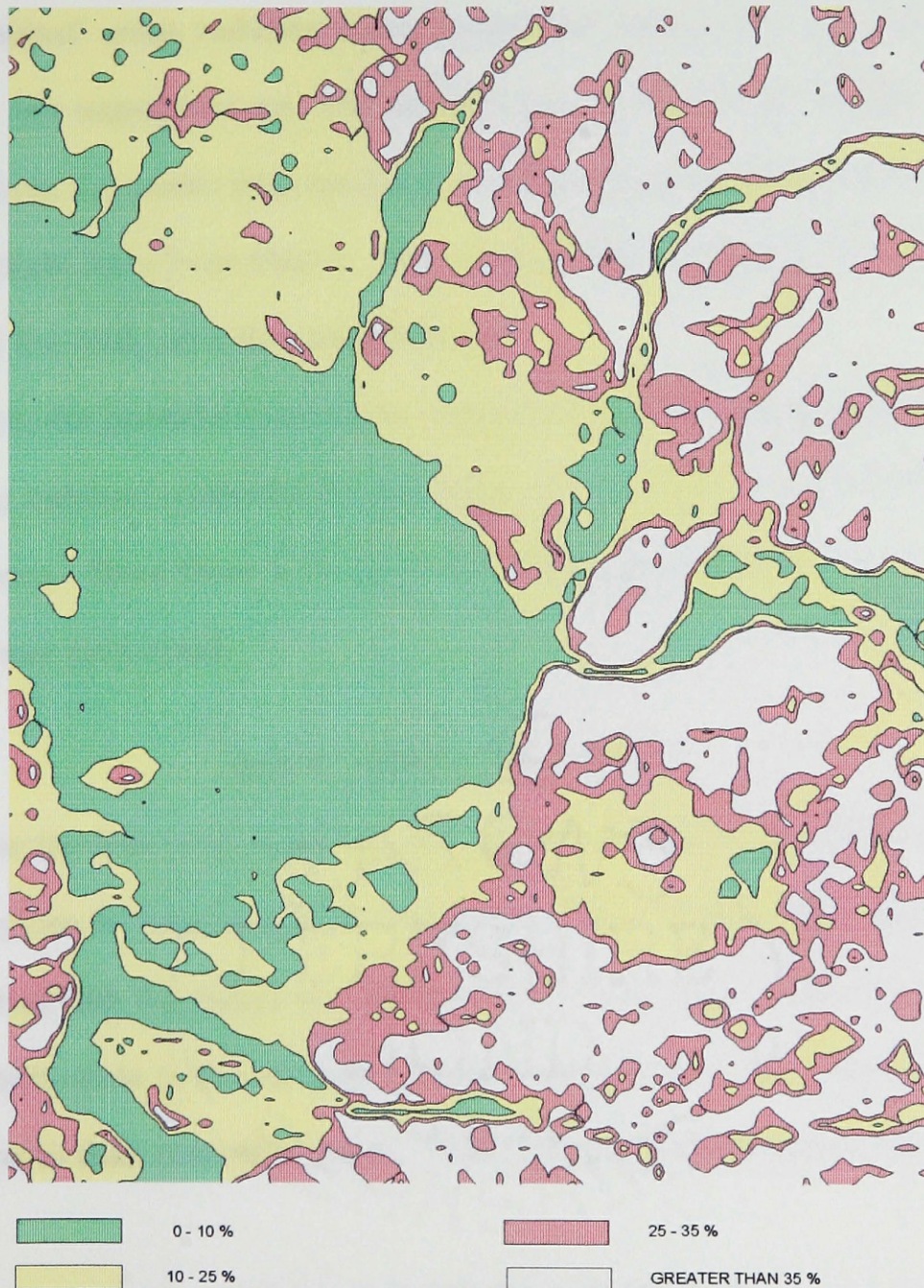
MISSOULA URBAN AREA



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SLOPE (PERCENT)

MISSOULA URBAN AREA



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overlay analysis for this example. This involves the implementation of several discrete steps as described below.

First, the urban area is overlaid on the base map in order to separate out the urbanized areas from among the census statistical units. In the process all of the "uninhabited" areas including water, forest land, barren land, agricultural and range land are segregated out. The adjusted base map is shown in Map 6.

Second, the public land use areas are superimposed on the adjusted base map to exclude them from Map 6. The result is Map 7 which shows all of the portions of the study area that are inhabited.

Third, the predicted population distribution pattern derived from the relationship between residential housing units and slope is compared with the inhabited area. Since there is no major difference between them, no overlay operation was performed.

Step 4: Attribute Data Analysis

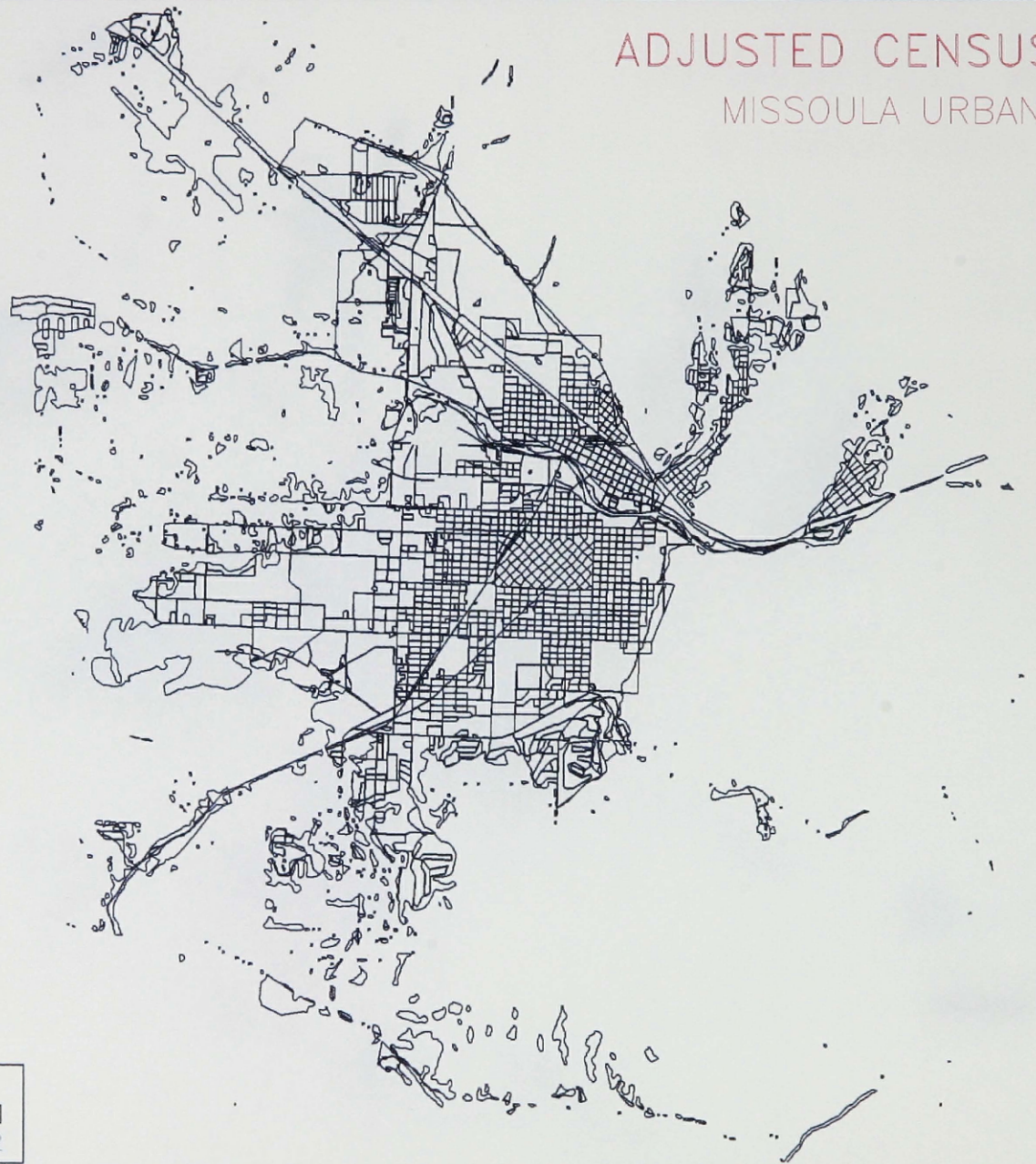
After the base map is altered, the attribute data still need to be manipulated before they can be merged with the base map. Most of these manipulations are accomplished with the **Select** and **Edit** module of Atlas GIS. There are several criteria which relate to the different situations which occur when reassigning populations to their respective areas. These criteria are discussed in the following listing.

1. Keep the original data for the completely inhabited blocks.
2. Reassign the total population of the whole block to the inhabited

MAP6

ADJUSTED CENSUS BLOCKS

MISSOULA URBAN AREA



MILES

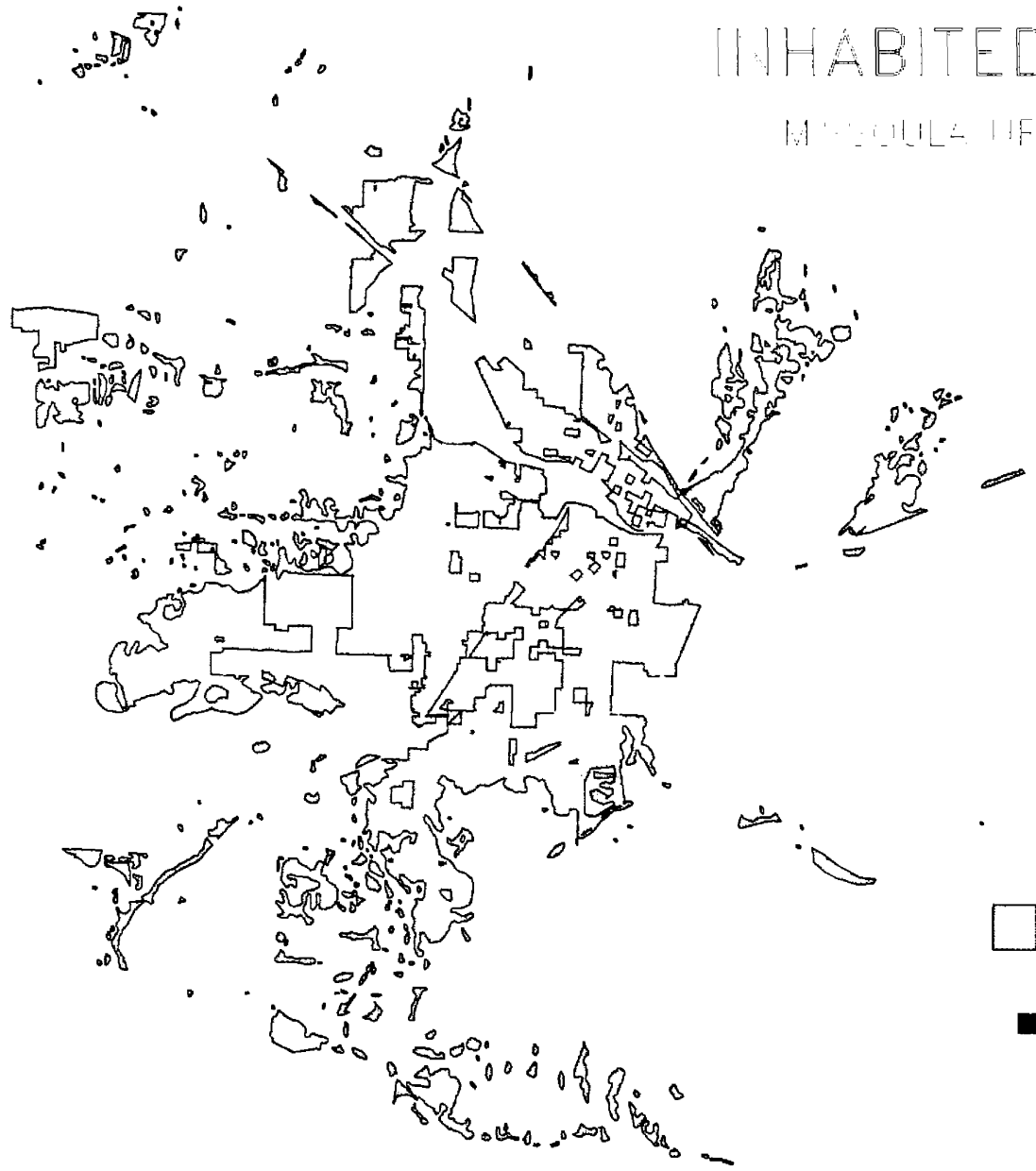


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MAP 7

INHABITED AREAS

MINOULA URBAN AREA



LEGEND



MILES



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area for the partially inhabited blocks.

3. Reassign population number proportional to the area of each inhabited unit for the blocks subdivided into several inhabited areas or districts.
4. Merge any contiguous inhabited remnant of a block to the adjacent block.
5. Add population counts to the nearest block for those commercial and public land use blocks which have only one or two households and low population counts.

Once the attribute data are reassigned to the adjusted base map, calculate population density (population number/land area) for all inhabited units.

Step 5: Spatial Analysis Based on the Attribute Data

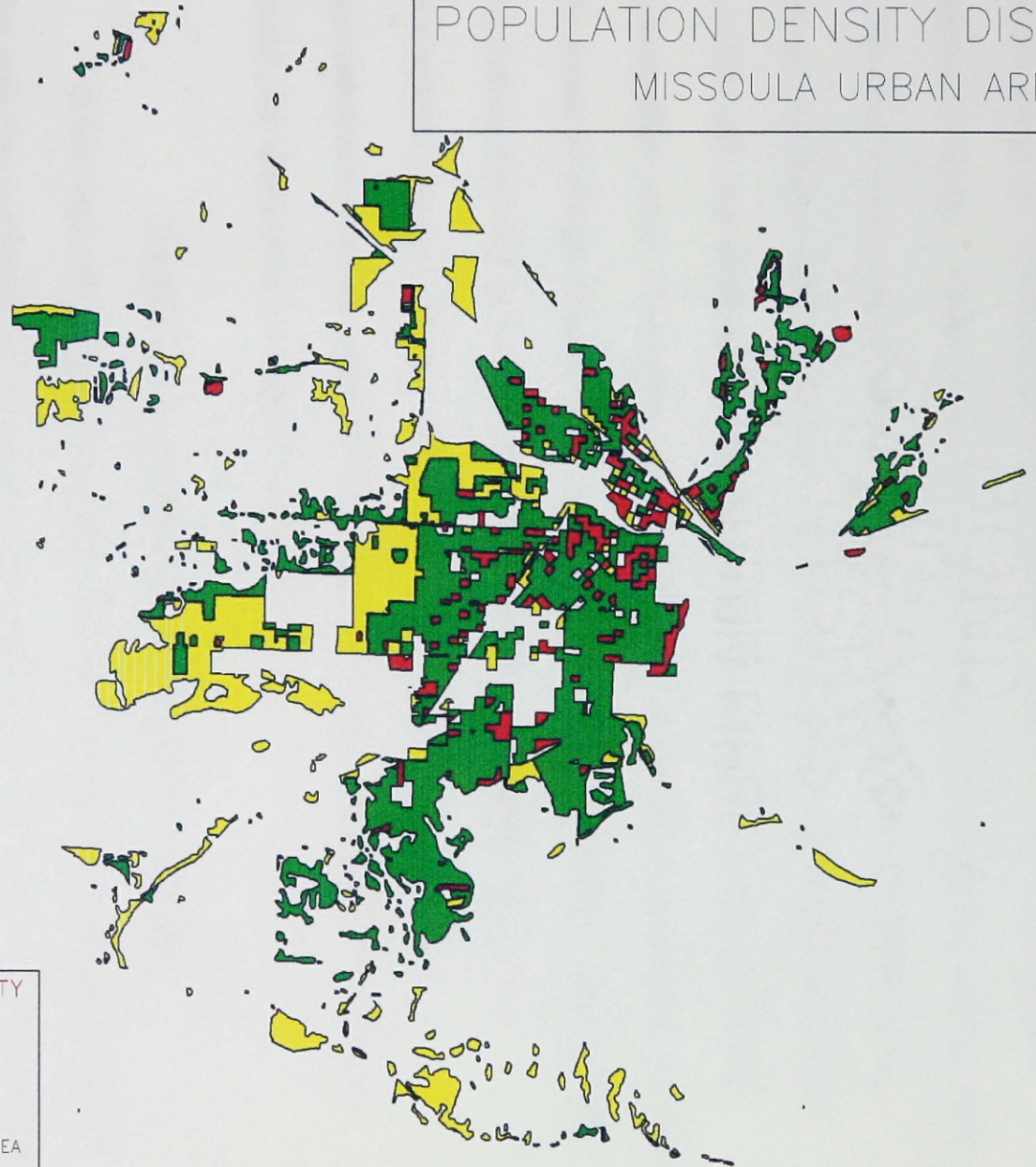
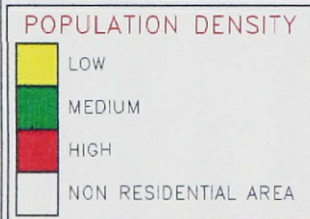
For the purpose of comparison, the same frequency distribution categories used for Map 1 (Table 4) are used for the dasymetric map. Based on the three categories, all areas having similar population densities and belonging to the same category are selected and united to form large uniform areas. Therefore, all unnecessary boundaries are eliminated.

Step 6: Making the Dasymetric Map

Atlas GIS's thematic mapping function is used to make the final Missoula urban area population density distribution map (Map 8). Although Map 8 is created by using the same data as that used for Map 1, it looks different from

MAP8

POPULATION DENSITY DISTRIBUTION MISSOULA URBAN AREA



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Map 1. The differences will be discussed in next section.

Comments on the Dasymetric Map

When one compares the dasymetric pattern (Map 8) with the choropleth pattern (Map 1), it is obvious that the former represents the actual density distribution better. Although the block patterns are retained in the central portion of Missoula's metropolitan area, this is understandable and acceptable since census population data are collected by individual block units which very likely coincide with the divisions of different population densities in densely settled metropolitan areas. Therefore, it is possible that street block boundaries are also the zones of abrupt change in the population density distribution. This is likely the reason that this section of the dasymetric map still looks somewhat choropleth. As for suburban and rural environments, the dasymetric representation is totally different from the choropleth map (Map 1). Without doubt, the dasymetric version is much better.

Possible Errors of Automated Dasymetric Mapping

It has been discussed above that automated dasymetric mapping includes not only the cartographer's work, but also the computer's work as it has resulted from communications between the two. Thus, errors are inevitable for automated dasymetric mapping because of the complicated processing involved. The errors can be recognized as three types: direct human, indirect human, and automated.

Direct Human Error

Direct human error refers those errors that originate with the cartographer. Since almost every step of dasymetric mapping requires the cartographer to make knowledgeable, but subjective, decisions, there exists the possibility of errors. With the help of a GIS, a huge amount of additional information can be used for dasymetric mapping. This additional information greatly assists the cartographer in decision making. If generous amounts of information are included into the process, the possibility of this type of error may be reduced at least partially.

Indirect Human Error

It is obvious that the accuracy of the map depends greatly upon the accuracy of the related databases. As noted previously, in addition to the original data, a great deal of additional information is required for dasymetric mapping. Both types of data may contain errors when they are collected and transformed. Often times, such data errors are not easy to detect and correct. Without question, potential errors of this type will be introduced in dasymetric maps which use such data. In order to differentiate these errors from the errors introduced by the cartographer, they may be referred to as indirect human error.

Automated Error

Since a GIS is the tool being used to implement dasymetric mapping, automated errors that affect either the spatial or the non-spatial attributes are inevitable. Automated errors mainly include polygon overlay errors, areal split and

aggregation errors, as well as attribute merging errors, etc. For example, the creation of sliver polygons almost always occurs as a result of polygon overlay operations. Of course, this constitutes an automated error. If these sliver polygons are not detected and eliminated properly, they may affect the accuracy of the final result. However, most GIS software packages have operational functions for error detection and elimination which tend to reduce such errors much to the benefit of automated dasymetric mapping.

Merits of Automated Dasymetric Mapping

As with many other applications, once a GIS is introduced into dasymetric mapping, the technique and the resulting maps will be improved in several ways. The main ones are: (1) increased accuracy; (2) simplified mapping procedures; and (3) popularized use of the technique.

Increasing Accuracy

With the help of a GIS, a great deal of the information required for dasymetric mapping can be accessed easily and rapidly by the cartographer. Much of this information is difficult to access and use without the help of the computer. Consequently, many useful variables were not used in traditional dasymetric mapping even though the cartographer knew that such data would be helpful. Now, the cartographer can access many kinds of additional information using GIS. This will not only help reduce human errors, but it will also improve the accuracy of dasymetric maps.

Another problem which arises more frequently is that of arbitrariness. This problem is so serious that some people have questioned the accuracy of traditional dasymetric technique.

"Dasymetric mapping is arbitrary in the sense that there is no obvious scale at which it should be applied. It has been shown that if the spatial resolution is too fine the cartographic product becomes unsatisfactory. This is not an indication that the derived data are themselves a poor product, merely that the method of cartographic presentation is at fault."¹¹

When making a dasymetric map manually, it is very difficult to process all required data at the same scale or level of generalization because some sources are more detailed than others. Therefore, scale is a problem that has substantially affected the accuracy of dasymetric maps.

Once a GIS is introduced into dasymetric mapping, however, this problem may in large part be solved. GIS stores and manipulates all required data for application at the same scale. Based on a comprehensive analysis of mapping phenomenon and the purpose of the map, the cartographer can make a decision about the scale at which the map should be produced. The overall result should be to decrease the arbitrariness of dasymetric maps and increase their accuracy.

Simplifying Mapping Procedure

As mentioned in the previous chapters, one reason that the traditional technique has been impeded is its excessive demand on time. With the help of a

¹¹M. Langfort and D. J. Unwin, "Generating and Mapping Population Density Surface within a Geographical Information System," *The Cartographic Journal* 31 (June, 1994): 26.

GIS, the cartographer can readily access a myriad of sources to select the best possible supporting information. Within a reasonable framework of time, the speed at which these operations can be performed should greatly facilitate application of the dasymetric technique to making dasymetric maps.

Popularizing Its Use

The dasymetric technique does produce more accurate approximations of distribution patterns than do choropleth maps. Still, the technique has not been utilized for mapping as many different kinds of phenomena as is possible. Of course, the problem is that the access to, and manipulation of, all required data is very difficult and time-consuming using traditional methods. But with the help of a GIS, the shortcomings of this technique will be diminished. Therefore, it is obvious that a GIS should help to popularize the use of this valuable thematic mapping technique.

Chapter Five

CONCLUSIONS

This chapter will first summarize what this study has accomplished. Based on this summary, some suggestions for the future design of a single piece of automated dasymetric mapping software will be given. Next, the limitations of this study will be reviewed. Finally, the tasks yet to be solved in automated dasymetric mapping will be discussed for the purpose of identifying some areas for future study.

What This Study Has Accomplished

The Description of Results

This study has carefully reviewed the dasymetric mapping technique--its varieties, uses, methodology and current situation of automation. At the same time, Geographic Information Systems have been examined with particular emphasis given to the methods and concepts that have the greatest bearing upon automated dasymetric mapping. The possibilities of automated dasymetric mapping have been seriously examined based on understanding the traditional thematic mapping technique and GIS. Among other things it has been revealed that making a dasymetric map is much more than a simple mapping process;

rather it is a complicated procedure that requires a great deal of geographic and attribute data analysis and manipulation. The study has revealed that many of the tasks involved in dasymetric mapping can be implemented using a GIS and has also demonstrated that not only is automated dasymetric mapping possible, but that it is already within our grasp. That is to say, although a mapping software package for automated dasymetric mapping is not yet available, the method can be implemented by using an assortment of GIS and mapping software packages which are already in existence.

Based on the positive answer to the possibilities of automated dasymetric mapping, a design adapting the traditional technique to available GISs and mapping software packages has been created. And then, this design has been demonstrated by using several of these software packages in order to build a dasymetric map of the population densities in the Missoula urban area. The GIS and mapping software packages used for this purpose include IDRISI, Atlas GIS and SURFER etc.

Conclusions

According to the work which has been accomplished by this study, the following conclusions can be made:

- 1) Automated dasymetric mapping is possible using a GIS.
- 2) Automated dasymetric mapping is different from automated choroplethic mapping and automated isoplethic mapping because a great amount of analysis of both the spatial and the non-spatial

attributes are involved.

- 3) Using a GIS for the purpose of automated dasymetric mapping will improve the quality of dasymetric maps and popularize its use by simplifying and enhancing the traditional method.
- 4) The computer can not automatically create dasymetric maps based on the original data. In other words, the cartographer must play an important role in automated dasymetric mapping. Without a thorough understanding of the principles of the traditional technique, it would be impossible to create a dasymetric map using a GIS.
- 5) For the best result, a GIS that has the capability of working with both raster and vector data structures is suggested for the purpose of automated dasymetric mapping.
- 6) A GIS used for automated dasymetric mapping must have a powerful user interface.

Some Suggestions for a Future Design

Although GISs can be used to accomplish automated dasymetric mapping, there is no single set of software designed specifically for that purpose. If such a piece of software were to be created, it would have to include a number of GIS functions as well as some standard computer mapping functions. The following list attempts to cover most of those functions:

- 1) **Ability to store, manipulate and display both raster and vector data,**

and to convert data format from one structure to another by using a variety of algorithms without losing the benefits of either format.¹

This requirement stems from the data requirement of dasymetric mapping technique which was discussed in Chapter Two. Since both raster and vector data structure are needed in automated dasymetric mapping, the automated dasymetric mapping software package should have the capability of working with both data structures.

- 2) **Ability to use a relational structure in conjunction with a separate vector data structure.** In a relational data structure, attribute information is kept separately from the topological information.² Since great amounts of both spatial and non-spatial attribute data analysis are involved in dasymetric mapping, separate data files should provide increased flexibility and ease of use.
- 3) **Full functionality of standard GIS functions, such as overlay, merge, split, statistics, search by attributes, etc.³** As discussed in Chapters Two and Three, all these functions are required by the spatial and

¹J. Hinton, "The best of both worlds: developing GIS for vector and raster data analysis," GIS Europe (November 1994): 33.

²J. Star and J. Ester, Geographic Information Systems: An Introduction (Englewood Cliff, NJ: Prentice Hall, 1990), 53-54.

³D. M. Clark and J. J. Kineman, "Global Databases: A NOAA Experience," in Building Databases for Global Science, ed. H. Mounsey and R. F. Tomlinson (Philadelphia, PA: Taylor & Francis, 1988), 228.

the non-spatial analysis involved in the dasymetric mapping technique.

- 4) **Integration with data base management system.** Data base management system provides the needed tools for accessing the databases. These tools include data storage, editing, merging, deleting, selecting, retrieving, etc. They are all very useful for automated dasymetric mapping, especially for the non-spatial attribute analysis involved in the dasymetric technique which was described in Chapter Two.
- 5) **Integration with the user interface.** Since the cartographer's participation in the mapping process is critical in dasymetric mapping (discussed in Chapter Three), the user interface is an indispensable element of automated dasymetric mapping. This function will allow the cartographer to communicate with the computer. Without the cartographer's participation and decisions, the dasymetric mapping would be impossible even with the help of a computer.

Limitations

It has been pointed out that "within a GIS, production of a dasymetric map is not a trivial problem, but equally is not impossible".⁴ This study has shown how

⁴P. F. Fisher, "Knowledge-based Approach to Determining and Correcting Areas of Unreliability in Geographic Databases," in The Accuracy of Spatial

to approach automated dasymetric mapping using existing GIS packages.

Nevertheless, this implementation has had to use several different algorithms from different packages. The reasons for this are: (1) the data required by dasymetric mapping originate from both structures: raster (e.g. satellite images) and vector (e.g. Census data), and (2) for this study, the author did not have access to the UNIX version of ARC/INFO which is capable of working with both raster and vector structures. Thus, when converting data from one structure to another and when importing and exporting them from one package to another, the accuracy of the data structures and the final dasymetric map might be affected. Also, efficiency would be affected. If the forms of both raster and vector structures are found in a single GIS, as well as the structure conversion routines and appropriate analysis tools for each data type, then the data could be stored in their original forms. This would minimize the amount of processing time involved and the number of possible errors. This would also permit analytic procedures to operate on a data structure where efficiency and accuracy are highest.⁵ In other words, the advantages of both data structures would be fully used in the process of automated dasymetric mapping.⁶ Therefore, this kind of GIS will probably make automated dasymetric mapping easier and more accurate than the work done by

Databases, ed. M. Goodchild and S. Gopal (Philadelphia, PA: Taylor & Francis, 1989), 49.

⁵J. Star and J. Ester, Geographic Information Systems: An Introduction (Englewood Cliffs, NJ: Prentice Hall, 1990), 59.

⁶See Chapter Three, Table 2.

this study.

The Tasks to be Solved

This study has specified a design which shows how automated dasymetric mapping can be accomplished using GIS. This design is most useful for one kind of dasymetric map—the choropleth dasymetric map because it was the method chosen for this study. The design was tested on population density distribution mapping.

Besides choropleth dasymetric maps, there are still two other types of dasymetric maps:⁷ pure dasymetric maps and density zones outlining dasymetric maps. The methods of compilation involved in these two types of dasymetric maps are similar to, but not the same as, choropleth dasymetric maps. All methods regarding different types of dasymetric maps have been separately described in Chapter Two. Therefore, a series of more or less related as well as different designs may be needed in order to completely implement automated dasymetric mapping.

As mentioned earlier, population density distribution is the most popular theme for dasymetric mapping; but it is not the unique theme for this traditional technique. There are still many others to which dasymetric mapping technique could be applied.⁸ Therefore, this design should also be tested on the other

⁷Since highly general dasymetric maps (see above, p12) have already become out-dated, we leave this type out.

⁸See Chapter Two, p20.

themes in order to derive the best overall design.

In summary, there are still many tasks to be solved in order to completely implement automated dasymetric mapping. However, this study is the first attempt to seriously deal with how the automation of this traditional technique can be implemented.

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